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SOLID WASTE DISPOSAL

RADIAN CORPORATION

PREPARED FOR
ENVIRONMENTAL PROTECTION AGENCY

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The report gives results of an investigation of available disposal technologies for nine solid wastes destined for land disposal. Purpose of the investigation was to examine the potential applicability of these already developed technologies to the disposal of sludges generated by flue gas desulfurization systems. For each material of interest, including scrubber sludge, the nature of the waste, traditional disposal procedures, and related environmental effects are described. Case studies were examined in order to quantify the problem as much as possible; results of these studies are included in the report.

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SOLID WASTE DISPOSAL
FINAL REPORT

by

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TABLE OF CONTENTS

Page

CONCLUSIONS vii

EXECUTIVE SUMMARY ix

1.0 INTRODUCTION.................................... 1

2.0 MUNICIPAL WASTE DISPOSAL.......................... 4
2.1 Nature of Municipal Waste.......................... 4
2.2 Disposal of Municipal Wastes....................... 7
2.2.1 Sanitary Landfill................................ 8
2.2.2 Composting....................................... 11
2.2.3 Incineration..................................... 11
2.2.4 Pyrolysis.. 13
2.2.5 Resource Recovery................................ 14
2.3 Case Studies of Municipal Waste Disposal........... 16
2.3.1 Sonoma County Central Solid Waste Disposal Site... 16
2.3.2 Sonoma County Refuse Test Cells.................. 20

3.0 SEWAGE SLUDGE DISPOSAL............................ 32
3.1 Nature of Sewage Sludge............................ 32
3.2 Pre-Disposal Treatment and Handling................ 37
3.2.1 Sewage Sludge Dewatering......................... 37
3.2.2 Sewage Sludge Handling........................... 40
3.3 Disposal Techniques................................ 42
3.4 Case Study - The Prairie Plan...................... 45

TABLE OF CONTENTS CONTINUED

Page

4.0 GENERAL ORE WASTES.................................. 54
4.1 Nature of the Waste.................................. 54
4.2 Disposal Methods.................................. 55

5.0 CULM PILES.................................. 59
5.1 Nature of the Waste.................................. 60
5.2 Conventional Disposal Technology.................................. 64
5.2.1 Disposal Site.................................. 64
5.2.2 Disposal Procedures.................................. 64
5.2.3 Environmental Aspects of Culm Piles.................................. 68
5.3 Alternate Disposal Technologies.................................. 72
5.4 Case Studies - Culm Pile Reclamation.................................. 74

6.0 PHOSPHATE SLIMES.................................. 85
6.1 Phosphate Mining and Beneficiation.................................. 85
6.2 Nature of Phosphate Rock Slime.................................. 88
6.3 Phosphate Slime Disposal Techniques.................................. 91
6.3.1 Conventional Method.................................. 91
6.3.2 Alternate Disposal Methods.................................. 94
6.4 Environmental Aspects of Phosphate Slimes Disposal. 97
6.5 Case Study - Reclamation of Slimes Disposal Area... 99

7.0 TACONITE TAILINGS DISPOSAL.................................. 101
7.1 Nature of Taconite Tailings.................................. 101
7.2 Disposal Techniques.................................. 106
7.2.1 On-Land Disposal.................................. 106
7.2.2 Lake Disposal.................................. 108
7.3 Case Study - Erie Mining's Tailings Reclamation Program.................................. 108

TABLE OF CONTENTS CONTINUED

Page

8.0 GYPSUM FROM PHOSPHORIC ACID MANUFACTURE............ 118
8.1 Nature of By-Product Gypsum........................ 121
8.1.1 Chemical and Physical Properties.................. 121
8.1.2 Production Quantities of Waste Gypsum............. 125
8.2 Conventional Disposal Practices..................... 126
8.2.1 Description of Methods............................ 126
8.2.2 Environmental Aspects of Phosphogypsum Disposal.... 131
8.3 Alternate Disposal Methods.......................... 136
8.4 Case Study - Phosphogypsum Disposal................. 140

9.0 ACID MINE DRAINAGE SLUDGE........................... 142
9.1 Nature of AMD Sludge................................ 143
9.2 Disposal Techniques for AMD Sludge.................. 146
9.2.1 AMD Sludge Conditioning........................... 147
9.2.2 Dewatering Techniques............................. 149
9.2.3 Sludge Handling................................... 151
9.2.4 Ultimate Sludge Disposal.......................... 152
9.3 Alternate Approaches................................ 153
9.4 Case Studies - Consolidation Coal Company.......... 155
9.4.1 Whetstone Portal Treatment Plant.................. 156
9.4.2 Edgell Treatment Plant............................ 159
9.4.3 Levi Moore Treatment Plant........................ 161

10.0 COAL ASH... 163
10.1 Nature of Coal Ash................................. 163
10.1.1 Properties....................................... 163
10.1.2 Quantities....................................... 174
10.2 Disposal Technology................................ 177
10.2.1 Ponding of Coal Ash.............................. 177
10.2.2 Landfill... 182

TABLE OF CONTENTS CONTINUED

Page

10.2.3 Deep Mine Disposal........ 183
10.2.4 Coal Ash Utilization........ 184
10.3 Case Study - Coal Ash Disposal At TVA's Widow Creek........ 195

11.0 SCRUBBER SLUDGE........ 205
11.1 Nature of the Material........ 205
11.1.1 Chemical and Physical Properties of Scrubber Sludge........ 206
11.1.2 Quantity of Sludge Production........ 210
11.2 Application of Conventional Disposal Techniques to Scrubber Sludge........ 213
11.2.1 Ponding........ 215
11.2.1.1 Technical Aspects........ 215
11.2.1.2 Environmental Aspects........ 218
11.2.2 Disposal by Landfill........ 222
11.2.2.1 Technical Aspects of Landfilling Sludge........ 223
11.2.2.2 Environmental Aspects of Landfilling Sludge........ 234
11.3 Alternate Disposal Techniques........ 240

12.0 BIBLIOGRAPHY........ 247

CONCLUSIONS

The results of this case-study type of approach to the problem of lime/limestone scrubber sludge disposal are summarized below:

(1) Much of the technology already developed for ponding of phosphate slimes, by-product gypsum, taconite tailings, coal ash, and acid mine drainage sludge is applicable to scrubber sludge disposal by ponding.

(2) Technologies developed in the area of land disposal of sewage sludge, coal ash, and possibly acid mine drainage sludge that is removed from sludge ponds during desludging operations may be applicable to scrubber sludge disposal, particularly in cases where fixation technology has been applied.

(3) Alternative disposal methods available for scrubber sludge, including deep mine disposal, strip-mined land reclamation, and utilization, possess some degree of potential. Comparable technologies in these areas are now under study for AMD sludge, coal ash, sewage sludge, and by-product gypsum.

(4) Sludge handling techniques currently in use for by-product gypsum, acid mine drainage sludge, and several other wastes included in the present study can be applied to handling scrubber sludge.

(5) Potential leachate problems associated with scrubber sludge disposal can be further defined by results of several in-progress investigations described in this report.

(6) Reclamation of waste disposal areas is being conducted by several industries on a large scale. Techniques have been developed, or are in the process of development, for culm piles, taconite tailings, phosphate slimes, and sanitary landfills. Much of the experience gained in these projects may be applicable to reclamation of scrubber sludge ponds or landfills. Future work is needed in this area.

(7) Based on presently available data, there are no insurmountable technological problems in disposing of scrubber sludge in an environmentally acceptable manner.

EXECUTIVE SUMMARY

1.0 INTRODUCTION

Disposal of sulfur oxide sludges generated by flue gas desulfurization systems is currently under investigation by the Environmental Protection Agency and the utility industry. Radian Corporation, under contract to EPA, has been involved in the preparation of several documents dealing with this issue (Contract Nos. 68-02-1319, Task No. 1, "Information on the Status of Lime/Limestone Sludge Handling"; 68-02-0046, Task No. 12, "Utilization of Stack Gas Cleaning Equipment in Ohio"; and 68-01-2008, "Prepare a Technology Transfer Process Design Manual"). The reports generated from the last two programs listed are to be released shortly. During the course of those studies, the magnitude of the problem faced by the electric utility industry was estimated and briefly compared to similar waste disposal problems encountered in other areas. This document is an expansion of the comparison made at that time.

The purpose of the present investigation is to identify available technologies developed in other industries that may be applicable to scrubber sludge disposal. The general nature of the problem, disposal technologies, and environmental aspects for each of nine solid wastes destined for land disposal are presented in this document. Those aspects potentially applicable to the present problem were emphasized. The quantities, composition, and typical disposal methods for each material included in this study are summarized in Table I.

A case study approach was employed to obtain information related to specific problems encountered, ability of the technique to meet local environmental standards, and alternatives or modifications under consideration if the current method has

TABLE I

SUMMARY OF WASTES AND DISPOSAL TECHNIQUES

Waste	Typical Composition	Annual Production Metric Tons	Disposal Technique	Environmental Impact	Aspects Potentially Related To Scrubber Sludge Disposal
Municipal Refuse	Paper, plastic, glass, wood, metal, textiles, garbage etc.	360,000,000 (1973)[1,2]	Landfilling, composting, incineration, pyrolysis, resource recovery	Potential surface and groundwater pollution; air pollution; odor, subsidence; fire; health hazards in worst cases	Leachate Control
Sewage Sludge	0.1-15% solids Typical solids analysis,% (digested sludge)[3]: Volatile matter 45-60 Ash 40-45 Insoluble ash 35-50 Greases, fats 3-17 Protein 16-21 NH_4NO_3 1-4 P_2O_5 0.5-3.7 K_2O 0-4 SiO_2 20-22 Fe 5.4 Cellulose 10-13	55,000,000 (1980)[2]	Land disposal, composting, incineration, pyrolysis, permanent lagooning, ocean dumping	Potential surface and groundwater pollution; air pollution (incineration)	Application to reclamation of acid mine spoil; natural leachate filtering system; sludge handling and transport.
General ore Wastes	Rock wastes from mining operations	1.3 billion[4]	Surface piles, landfill	Potential water pollution; aesthetic considerations	General siting considerations
Culm Piles	Waste coal, slate, bone, carbonaceous and pyritic shales, clay, trace metals	91,000,000 metric tons of bituminous waste (1969)[5]	Surface piles	Surface and groundwater pollution (acid drainage and siltation); air pollution from spontaneous combustion (SO_2, H_2S, CO, particulates)	Reclamation technique and economics, especially use of fly ash and AMD sludge as soil conditioners and neutralizing agents.
Phosphate Slimes	4-6% solids Solids analysis,%[6]: P_2O_5 9-17 SiO_2 31-46 Fe_2O_3 3-7 Al_2O_3 6-18 CaO 14-23 MgO 1-2 CO_2 0-1 F 0-1 LOI[7] 9-16 BPL[8] 19-37	38,000,000[9]	Ponding	Potential surface and groundwater pollution; possible permanent bogs (final settled solids content 30%); potential dam failures.	Dewatering techniques; reclamation procedures

TABLE I (Cont.)

SUMMARY OF WASTES AND DISPOSAL TECHNIQUES

Waste	Typical Composition		Annual Production Metric Tons	Disposal Technique	Environmental Impact	Aspects Potentially Related To Scrubber Sludge Disposal
Taconite Tailings	4-40% solids		55,000,000[11] (dry basis)	Ponding, lake disposal	Potential surface and groundwater pollution	Reclamation techniques for tailings ponds; handling and transport of slurry
	Solids analysis, %[10]:					
	Oxygen	46.40				
	Iron	14.93				
	Silicon	33.03				
	Aluminum	0.35				
	Calcium	1.67				
	Magnesium	2.55				
	Manganese	0.37				
	Titanium	0.030				
	Phosphorus	0.026				
	Sodium	0.20				
	Potassium	0.08				
	Sulfur	0.03				
	Carbon	0.11				
	Hydrogen	0.10				
	Lead	0.005				
	Zinc	0.004				
	Nickel	0.002				
	Copper	0.004				
	Molybdenum	<0.001				
	Vanadium	<0.001				
	Cobalt	0.002				
	Chromium	0.004				
	Cadmium	0.0003				
Gypsum from Phosphoric Acid Manufacture	65-82% solids as discharged from filter[12], settles to 85-90% solid[13]		25,000,000[13] (dry basis)	Ponding, surface piles, ocean disposal	Surface and groundwater pollution; air pollution (fluoride)	Dewatering techniques; utilization; pond operation
	Solids analysis, %[14]:					
	$CaSO_4 \cdot ½H_2O$	Negligible				
	$CaSO_4 \cdot 2H_2O$	92.84				
	$Ca_3(PO_4)_2$	2.25				
	CaF_2	2.66				
	SiO_2	0.95				
	Fe_2O_3	0.01				
	Al_2O_3	0.79				
	Other impurities	0.50				
Acid Mine Drainage Sludge	1-5% solids		8,200,000[15]	Ponding	Water pollution potential; possible permanent bogs	Sludge handling; pond operation; dewatering technology
	Solids analysis, %[15]:					
	$CaSO_4$	40				
	$MgSO_4$	5				
	CaO	3				
	SiO_2	20				
	MgO	1				
	Fe_2O_3	15				
	Mn_2O_3	4				
	Al_2O_3	12				
	Trace Metals					

TABLE I (Cont.)

SUMMARY OF WASTES AND DISPOSAL TECHNIQUES

Waste	Typical Composition	Annual Production Metric Tons	Disposal Technique	Environmental Impact	Aspects Potentially Related To Scrubber Sludge Disposal
Coal Ash	Ash analysis, %[16]: SiO_2 30-50 Al_2O_3 20-30 Fe_2O_3 10-30 CaO 1.5-4.7 K_2O 1.0-3.0 MgO 0.5-1.1 Na_2O 0.4-1.5 TiO_2 0.4-1.3 SO_3 0.2-3.2 C and volatiles 0.1-4.0 B 0.1-0.6 P 0.01-0.3 U + Th 0.0-0.1	38,900,000 (1971)[17]	Ponding, landfill, utilization	Potential surface and groundwater pollution	Potential water pollution problems, especially trace metals; utilities previous experiences in disposal procedures.
Scrubber Sludge	Typical Limestone Scrubber Sludge: H_2O 50% $CaSO_3 \cdot \frac{1}{2}H_2O$ 18% $CaSO_4 \cdot 2H_2O$ 2% $CaCO_3$ 6% Ash 24% Trace Metals	113,000,000 (1980)[18] (50% solids)	Ponding, landfill, possibly deep mine disposal or utilization	Potential surface and groundwater pollution; possible permanent bogs	

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[1] Exclusive of agricultural and mining wastes

[2] Personal communication, Norbert Schomaker, SHWRL, NERC, Cincinnati

[3] Source: EN-084

[4] Source: US-079

[5] Source: BU-086

[6] Source: BA-133

[7] Loss on ignition

[8] Bone phosphate of lime

[9] One-third of matrix mined during 1970. Source: US-064

[10] Source: RE-093

[11] Based on 100 million tons annual crude ore production, 25% iron content, 60% beneficiation

[12] Source: BO-095

[13] 80% disposed of in Florida. Personal communication, Mr. Stowalzer, U. S. Bur. Mines, Phosphate Commodity Office

[14] Source: GO-072

[15] Personal Communication, R. D. Hill, NERC, Cincinnati

[16] Source: RO-093

[17] Source: BR-118

[18] Tons of wet, ash-containing sludge (50% solids). Based on the following assumptions:
a) 116,000 MW of controlled generating capacity by 1980
b) 75% of control by lime/limestone systems
c) Coal: 3%S; 12% ash
d) Plant: 6400 hr/yr: 0.4 kg coal/kw-hr
d) Scrubber: 85% SO_2 removal; 1.0 CaO/SO_2(inlet) mole ratio; 1.2 $CaCO_3/SO_2$ (inlet) mole ratio

proven inadequate. This type of approach was used in order to quantify each problem as much as possible.

The general problem descriptions and case studies are presented in Sections 2.0 through 10.0 in the Detailed Report. Section 11.0 presents currently available data concerning the nature of scrubber sludge and a discussion of the applicability of disposal technologies developed by other industries to scrubber sludge disposal. The conclusions reached in this study are given in Section 12.0.

2.0 MUNICIPAL WASTE DISPOSAL

Municipal refuse has traditionally been disposed of by landfilling or open dumping. Alternate methods are now required because of mounting tonnages of waste being produced, decreased land availability, higher land costs, and increasing public concern with environmental issues. Methods now in use include sanitary landfill, incineration, pyrolysis, composting, and resource recovery (recycling).

Landfill operations still constitute the major form of municipal waste disposal. One source estimated that over 90% of the nation's solid waste is disposed of in this manner at ~12,000 individual sites. The term sanitary landfill is defined as "a method of disposing of refuse on land without creating nuisances or hazards to public health or safety, by utilizing the principles of engineering to confine the refuse to the smallest practical area, to reduce it to the smallest practical volume and to cover it with a layer of earth at the conclusion of each day's operation, or at such more frequent intervals as may be necessary". This type of operation should not be confused with open dumping, a practice which involves none of the above considerations and which is being prohibited in an increasing number of communities.

Potential environmental hazards associated with a sanitary landfill operation include groundwater contamination, gas generation, odor, subsidence, fire, and health hazards. Proper maintenance and operation of the landfill will effectively prevent most of these.

Groundwater contamination by landfill leachate has been the subject of numerous studies. Several experimental studies were designed to determine quantities, qualities, and movement of leachate. In general, climate, temperature, age of landfill, composition, and original water content are chief factors affecting leachate characteristics. Prevention of leachate problems is achieved by careful design in accordance with the topography and hydrogeology of the area. Currently, experimentation with sealing of landfills is being conducted; entrapped leachate is collected and treated, if necessary. This concept may become important in scrubber sludge disposal if leachate is shown to pose a hazard.

The aspect of municipal waste disposal having greatest relevance in the area of scrubber sludge disposal is leachate formation, migration, and collection. Two case studies were selected. The first is a full-scale landfill located in Central Sonoma County, California, where 650 metric tons of refuse are handled daily. The design feature of interest is the leachate control system which entails migration to the surface and subsequent evaporation or recycle through the refuse. Surface drainage is intercepted and diverted around the active portion of the site. County officials feel that this system of refuse disposal/leachate control adequately complies with all existing water quality standards.

Adjacent to the full-scale landfill at Sonoma County, a demonstration project is underway to investigate stabilization of refuse. The study is funded principally by EPA under Demonstration Grant No. G06-EC-00351 of the Office of Solid Waste Management Programs. Partial funding of the three-year project is provided by the County of Sonoma. The purpose of the investigation is two-fold:

(1) To investigate the stabilization of refuse in a sanitary landfill by analyzing leachate, gas, temperature, and settlement parameters.

(2) To determine the effect on refuse stabilization of applying excess water, septic tank pumpings, and recycled leachate to a sanitary landfill under various operational modes.

Five clay-lined, earthen test cells were constructed and are being operated under different sets of leachate generating conditions. Results to date indicate that the earth cells are effective in preventing water pollution from leachate.

This work suggests that techniques for leachate control which have been developed for municipal refuse disposal would be applicable to prevention of leaching of undesirable components from sludge which is disposed of in a landfill operation, assuming that further characterization of dewatered sludge shows that it is not subject to regaining moisture. Even if recycling of leachate is not feasible, the technology for leachate collection and landfill sealing would be applicable.

3.0 SEWAGE SLUDGE DISPOSAL

The disposal technology for sewage sludge having the greatest potential application to scrubber sludge disposal is reclamation of devastated land. The best example is the disposal system used by Chicago since 1971. The Prairie Plan involves barging 6,800 metric tons of digested sludge, at 3-5% solids, 300 kilometers from the treatment plant to southern Illinois. The sludge is spray-irrigated onto the fields at an appropriate irrigation time after temporary lagooning to reduce ammonia nitrogen and to allow aging.

A natural filtering system is relied upon to insure that water reaching surrounding streams is of high quality. As the sludge filters down through the crop roots, bacteria convert sludge nutrients to forms usable by the plant. Remaining liquor continues to pass downward until an impervious stratum is reached, at which point horizontal movement occurs. Farm fields are surrounded by hedge rows. Any nutrients seeping out of the field will be taken up by their extensive root systems. Monitored field detention basins collect all surface runoff. If not polluted, the water is released to a nearby stream. However, if quality is poor, then the entire contents are recycled through the field. Additional protection is provided by lines of hedges and trees along banks and streams. All streams entering and leaving the 7,000-acre (2,800 hectare) tract are monitored. Additional monitoring stations including reservoirs, springs, and wells are also checked regularly.

Although no results are yet available from the water monitoring program at the large scale site, a small demonstration study to investigate the nature of leachate from sewage sludge application to highly acidic spoil was conducted in 1966. Sponsors were the Metropolitan Sanitary District of

Greater Chicago and the U. S. Forest Service. The results indicated a need to apply sewage sludge at a rate great enough to effectively neutralize plot acidity in order to prevent dissolution of metals added with the sludge.

Disposal of sewage sludge by application to acid mine spoil thus far appears to be a promising approach to this problem. Results indicate that crop yields are markedly improved, that acid stream pollution can be effectively reduced, and that the devasted land can be returned to productive use. Future results will provide more detailed insight into potential contamination of groundwater by trace metals released from the sewage sludge itself.

The applicability of the technology developed during these particular projects to scrubber sludge disposal lies in the potential application of scrubber sludge to acid mine spoil as a neutralizing agent and possibly a soil conditioner. Additional information on this subject is presented in the sections on culm bank reclamation with fly ash and acid mine drainage sludge. Also of significance in this study is the extent of effectiveness of a natural filter system to remove potentially contaminating species from leachate (in this case, the irrigating water) prior to reaching an aquifer system.

Another aspect of sewage sludge disposal potentially applicable to scrubber sludge is transport technology (piping and barging).

4.0 GENERAL ORE WASTES

The waste material included as general ore wastes includes both overburden and tunnel rock produced by the mining industry, exclusive of coal and other fuels. Tailings, the finely ground rock removed during milling operations, are not included in this category.

Disposal practices for rock mining wastes are not very sophisticated. There are three options normally available. Of 3.0 billion metric tons of overburden produced by the total surface mining industry in 1966, much was simply redeposited in the mined-out areas. Approximately 10% was used in the construction of dams for tailings ponds. The third alternative involved just heaping the waste in piles near the mine; these piles are referred to as waste banks or surface piles.

The pertinent environmental aspects associated with these disposal practices include loss of stability in the piles, reclamation, and erosion. The biggest problem thus far is the aesthetic issue. Contamination of groundwater by leachate has not been studied. One source reported that the soluble components of waste rock are a minor source of trouble, the only problem being with heavy metals. If the dump is properly sited and managed, however, any metal dissolution can be effectively prevented from leaving the immediate area. The chief problem in potential surface water contamination is with siltation and turbidity.

For aesthetic considerations, the pile should be located away from the main lines of traffic and below the horizon. The area should be constructed and contoured so that it blends in with the scenery as much as possible. Vegetation should be as complete and as rapid as possible.

Reclamation also prevents wind and water erosion and provides stabilization. Site surveys prior to placement of the refuse will locate near-surface water tables and permeable soil areas, the combination of which should be avoided to prevent groundwater contamination.

Because of the lack of any highly developed technology for disposal of this waste, no case study is presented.

5.0 CULM PILES

The disposal method for coarse preparation coal plant waste traditionally involves transport to a disposal site where the material is spread and compacted to achieve stability. The piles are referred to as culm piles (or banks), gob piles, or refuse banks. Reclamation techniques are now commonly practiced. Procedures and costs incurred by the coal-mining industry have been surveyed by the Bureau of Mines. The results showed that total costs for reclamation ranged from $1,800 to more $15,000 per acre. Refuse preparation costs ranged from $772 to $5,550 per acre. Soil covering and planting costs ranged from $1,083 to $5,086 per acre. Normal reclamation techniques consist of spreading and compaction, soil covering, and revegetation. In an effort to reduce costs associated with providing a soil cover for the waste, the Bureau is currently investigating the use of fly ash, acid mine drainage sludge, and other wastes as soil-substitute for cover. Estimates for reclamation costs using this new technique are approximately $350/acre, exclusive of land leveling expenses.

Three such projects were included in the present report as case studies. Results to date have been very successful both in reducing reclamation costs and in improving the ability of the soil to support vegetation.

Several environmental issues exist with respect to the disposal of coal refuse in conventional culm piles. One of the most extensively studied problems is air pollution from burning refuse piles. Also, there is the coal industry's problem of acid mine drainage. Waste coal refuse containing pyrite will generate significant amounts of sulfuric acid and iron sulfate in the presence of air and water. To control this problem, several approaches are being tested: neutralization of waste material; and sealing pile to prevent contact of water and air with acid-forming materials. Other environmental problems include physical degrading phenomena such as surface erosion and bank instability. Aesthetic objections also must be contended with in many situations; these are related to land use aspects.

This work suggests that reclamation techniques and costs developed for culm piles may be applicable to reclamation of landfills used for the disposal of scrubber sludge. In addition, a potential exists for utilization of sludge/ash mixtures as neutralizing agents and soil conditioners for culm material and acid mine spoil.

6.0 PHOSPHATE SLIMES

Phosphate rock slimes are the fine wastes, usually minus 200 or 150 mesh, discarded from the washer in the beneficiation process as a 4-6% solids pulp. The phosphorus content of the solids is often as high as in the original matrix, 9-17% (BO-074, BA-133). However, because of its extreme colloidal and hydrophilic nature which greatly hinders dewatering, attempts to beneficiate this slime have not been very successful.

The traditional method of slimes disposal is ponding in dammed, mined-out areas where they settle quite rapidly to 10-15% solids. However, the rate is so slow beyond this point that even after two years, the solids content is usually only 25-35% (BA-133, US-027). For every hectare-meter of matrix mined, 1.25 hectare-meters are required for slimes disposal. This means that in order for the mining area to provide sufficient storage space, dams must be built to increase the site's capacity. Some dams are constructed to retain slimes up to 12 meters deep. The ponds are built to rigid specifications normally out of quartz-sand tailings from the flotation effluent and overburden.

Water recycle is a very important aspect of slimes disposal and phosphate mining in general. The water leaving the plant with the slimes accounts for about one-half of the total water requirements for both the mining and beneficiation processes. About 10% of the water used in disposal is retained by the solids even after many years of settling. This is a tremendous draw on the water resources, thus providing heavy incentive for maximum water reuse both for environmental and economic reasons. Water is recycled continuously, but the rate of drawdown varies with the rate of production of the processing plant, pond area, river pollution, rainfall, winds, amount of freeboard, and possible hurricanes.

Studies of additional methods of phosphate slimes disposal have centered around improved and novel dewatering techniques. Investigations have been conducted by industry, TVA, and the Bureau of Mines. In general, the conclusions of almost all studies indicate that the dewatering techniques are not practically applicable to the industry's problem because (1) they require too much energy (chemical, mechanical, or thermal) thus making the processes uneconomical, (2) the dewatered products have no potential utilization, and (3) the best results obtained still only achieve a 50% solids material.

The environmental effects of phosphate slimes disposal by ponding were studied in several Florida river systems around 1950 (SP-034) and more recently in a North Carolina estuary (CA-125). In general, no evidence of harmful effects from clarified slimes liquor have been found with the possible exception of increase in algae growth which could indirectly cause eutrophication. Most phosphate mining companies monitor streams below their plants on a daily basis. The parameters measured include water flow, suspended solids, phosphate, and fluorine. No reports of groundwater monitoring were available.

Another potential hazard associated with phosphate slimes disposal by the conventional method is dam failure. Loss of the low solids slime over acres of adjacent land following dam failure has occurred several times in the Florida phosphate fields generating substantial legal action. Consequently, the dams are monitored constantly so that any structural weaknesses may be detected early.

Reclamation of slimes disposal ponds has presented the only constraint on freely planned development of former phosphate mining sites since they do not possess the support necessary for housing. However, they have been successfully converted to forested parks, greenbelts, and recreational areas. One reclaimed slimes disposal area visited by Radian personnel is now an 18-hole golf course. Reclamation procedures consisted of pumping tailings onto the slimes to achieve dewatering. Revegetation in this case presented few problems. The tailing material was contoured and seeded with bermuda type grasses and native shrubs and trees. Fertilization requirements were minimial owing to the high phosphate content in the tailing material.

Even unreclaimed slime ponds are not of zero value. They generally become heavily vegetated, marshy areas forming habitat for game birds and animals as well as a large population of snakes, rodents and predators. The combination of high fertility, low toxicity, and subtropical climate encourage verdant growth in all cases.

Several areas of phosphate slimes disposal are potentially applicable to scrubber sludge. Although the two materials are chemically dissimilar, the physical properties appear to be similar in several respects. In both cases, water recycle is very important, especially for scrubber sludge if the trend toward closed-loop operation continues. Both materials have relatively poor settling properties compared to tailings, for example. This is especially true for phosphate slimes. Extensive research in dewatering this material has been conducted and results to date have not yielded any completely effective method for the colloidal slimes. The most recent development is the mixing of slimes and sand tailings to achieve better settling; the mechanism is not completely understood, but may prove applicable to scrubber sludge dewatering. Possibly, fly ash, which possesses good settling characteristics, may promote sludge dewatering. Other dewatering technologies developed for testing of slimes also may be applicable to scrubber sludge.

Another physical property of dewatered slimes is its relatively low load-bearing capacity. Preliminary laboratory studies with untreated scrubber sludge, have produced varying results; however, fixation processes impart greater material strength properties to the waste. If scrubber sludge is shown to be a weak structural support, reclamation techniques and land use plans developed for slimes areas may be applicable to sludge disposal sites.

7.0 TACONITE TAILINGS

Two general methods are in use for the disposal of taconite tailings. The first and most prevalent is ponding with eventual reclamation of the tailings ponds. The second, used solely by Reserve Mining, is direct disposal into Lake Superior.

The taconite plants using on-land disposal generally use ponds with dams or dikes constructed from tailings. In the case of the Erie Mining plant, coarse tailings are sluiced directly to either a 1,300 acre (500 hectare) or a 700 acre (300 hectare) settling pond. The tailings fines are passed through thickeners and then discharged to the ponds. Water is recycled. The Eveleth plant also operates on a closed loop basis. In this case the coarse tailings containing 17-20% water are separated and hauled by truck to the pond site for dike construction. The fines go to a hydroseparator and then to a thickener before discharging to the tailings pond. In this case the use of coarse tailings for dike construction reduces dusting problems. Pond waters are recirculated to the plant.

The Erie plant has been the subject of rather extensive experimentation in reclaiming tailings ponds. The company has instituted a "Multiple Resource Management Plan" designed to utilize the following resources: minerals, water, wildlife, and recreational uses. During studies conducted to determine the optimum methods for stabilization of dikes constructed from tailings, the conclusion was reached that while the tailings are not toxic to plant life, their fertility is very low. Through a planned program of fertilization, seeding and mulching, it has been possible to revegetate tailings basins within a single growing season following spring planting. Although the revegetation research is still incomplete, it has been noted that native trees are beginning to reestablish. The main vegetation is still alfalfa, however. The fine nature of the tailings have required the planting of low plants with strong root systems to stabilize the soil. During 1967 and 1971 approximately 100 acres (40 hectares) of basin were reclaimed. These initial results, although modest, are promising but much research remains before reclamation of infertile tailings basins becomes routine.

The relevance of this work to scrubber sludge disposal lies in the so-far successful reclamation of a disposal site for a non-vegetative-supporting material. To date, there has been no investigation of the ability of untreated or stabilized scrubber sludge to support vegetation or of its phytotoxicity.

8.0 GYPSUM FROM PHOSPHORIC ACID MANUFACTURE

In the manufacture of phosphoric acid by the wet process, phosphate ore is contacted with sulfuric acid resulting in gypsum precipitation. For every metric ton of phosphate rock processed, 1.5 metric tons of by-product gypsum are produced. Similarly, for every metric ton of P_2O_5 product, 4.5 metric tons of gypsum result. The gypsum is filtered from the system, and the filter cake is then washed and discharged from the filter containing 18-35% free moisture.

In most operations in this country, the by-product gypsum is treated as a waste and traditionally disposed of in diked ponding areas. The pond area should be 0.5 acres per daily ton P_2O_5 production (0.2 hectares per daily metric ton P_2O_5 produced). The rate of gypsum accumulation is approximately one acre-foot per year per daily ton P_2O_5 (~0.1 hectare-meters per year). As the solids settle, the supernatant is recycled and the settled solids may be used to build up the height of the dikes. Some dikes have been built up as high as 30 meters. The disadvantages of this practice include the necessity of mechanical rehandling and increased slurry pumping costs. The potential utilization of scrubber sludge in this capacity has not yet been determined.

Water reuse is a very important aspect of the phosphate industry because of the huge quantities required in the mining operations. While ~80% water recovery is generally achieved, some is released to the environment, especially during periods of heavy rainfall. The composition of the supernatant changes in the pond until equilibrium is reached, at which time the results shown in Table II are typical. Prior to discharge, adjustment of pH, fluoride, and phosphate is necessary. The

TABLE II

TYPICAL EQUILIBRIUM COMPOSITION OF GYPSUM POND WATER (BA-133)

Contaminant	Concentration, mg/ℓ
P_2O_5	6000-12,000
Flouride	3000-5000
Sulfate	2000-4000
Calcium	350-1200
Ammonia	0-100
Nitrate	0-100
pH	1.0-1.5

exceptions are plants situated where evaporation rates are very high, regulations are less than stringent, or the subsurface drainage rate is high. In most cases the treatment consists of lime neutralization and settling. Double liming, or even triple liming, is usually required to achieve the necessary degree of impurity removal.

Although groundwater contamination from gypsum pond leachate and runoff is a potential hazard, no data are available. However, no harmful effects have been detected to date by state or federal agencies.

The case studied is typical of the U. S. phosphate fertilizer industry's practices for disposing of by-product gypsum. Mobil Chemical's facilities in Polk County, Florida, were visited by Radian personnel to obtain first-hand information in this subject area.

Alternate disposal methods for phosphogypsum entail various utilization schemes, some of which are quite highly developed in countries other than the United States. Because of the abundant supply of natural gypsum deposits here, there has not been as strong an incentive to develop utilization technology as has been felt in Japan, Europe, and other areas. Other throwaway procedures used in other countries to varying extents include ocean- or sea-dumping and truck transport to landfill sites.

The future of these gypsum piles remains undetermined. Although the industry is promoting investigation of potential utilization of this by-product, no schemes appear commercially feasible at this time. Meanwhile, the gypsum stockpiles are continuing to build until a time when a feasible scheme is developed.

For this reason, no attempt has been made by the industry to reclaim these disposal sites; no information in this area is available although it would certainly prove very useful in assessing the reclamation potential of scrubber sludge disposal sites.

9.0 ACID MINE DRAINAGE SLUDGE

Acid mine drainage is a significant environmental problem of the mining industry, especially coal mining. This water pollution results when naturally occurring pyrite, FeS_2, in the coal seam and wastes is oxidized in the presence of air and water to form sulfuric acid and soluble iron [Fe(II) and Fe(III)] sulfates. Such mine drainage (AMD) is typically very acidic (pH 2 to 3) and must be treated for pH and dissolved iron before release to surrounding water courses.

Most treatment processes are based on neutralization of the acidity and oxidation and subsequent precipitation of the iron. Neutralizing agents in common use are lime, hydrated lime, and to lesser extents, (mostly on an experimental basis) limestone. A sludge with a typical solids content of 1% by weight results. Under extensive periods in storage basins, final solids content of 13.9% has been achieved. Pilot plant data for clarifier underflow indicate that a solids content of almost 5% can be achieved. However, results are highly dependent on neutralizing agent used, pH, and aeration. These results show that AMD sludge possesses poorer settling properties than scrubber sludge. Information concerning conditioning, dewatering, handling, and ultimate disposal of AMD sludge is potentially applicable to scrubber sludge.

The majority of AMD neutralization plants dispose of their partially dewatered sludges in lagoons where natural evaporation, freezing, and percolation further reduce the water content. In the past, a primary settling area and a permanent sludge impoundment were favored. Now the trend is toward a single ponding area which receives sludge at one end and discharges effluent supernatant at the opposite side. The volume requirements for a ponding arrangement depend primarily on the extent of dewatering achieved prior to ultimate disposal. For example, a 5-6% solids sludge would require approximately one-third of the volume of drainage water treated. After an extended period in a secondary settling pond, the resultant 13.9% solids sludge requires only 3% of the volume of drainage treated. The sludge will continue to settle and compact until equilibrium is reached; i.e., when the weight of solids equals the strength of the flocs.

There is an increasing use of inactive deep mines as sludge disposal sites. The waste is either trucked or piped to boreholes through which it is injected. The alkaline sludge reportedly remains in solid form; also, little resuspension of dissolved solids occurs. These areas require further investigation, however.

Three typical acid mine drainage neutralization plants owned and operated by Consolidation Coal Company were visited during the present study. Hydrated lime is employed at all three sites, and the sludge is contained in earthen impoundments where the solids settle and clarified water is pumped to a stream. In two of the three cases, earth-filled dams were constructed to retain the sludge. The effluent from each plant is monitored on a weekly basis using grab sample techniques, as required by the state of West Virginia. Proposed effluent limitations for the coal industry as well as West Virginia limitations are being met by the neutralization treatments employed.

10.0 COAL ASH DISPOSAL

Basically there are three alternatives available for the ultimate disposal of solids from fossil fuel fired utilities: ponding, landfill, and utilization. The first two approaches, in which the solids are viewed as throw-away wastes, are discussed with special consideration given to the environmental aspects of each. Another alternative, deep mine disposal, is also briefly described.

Ash ponds are typically operated such that the slurry enters one end of a single pond. As it flows to the opposite side, the well-settling ash drops out and a pool of supernatant forms at the far end. The effluent is removed via weirs or standpipes, thus allowing continuous operation of the pond until full. In ash pond management, the settled ash is seldom used to increase the height of the walls because its spherical form results in a low angle of repose.

A second approach commonly taken by fossil fuel-fired utilities for solids disposal is landfill. This method eliminates the need for long distance hydraulic sluicing systems and on-site ponding facilities. The disposal area may be either on-site or off, again depending on land availability.

The pollution potential of an ash landfill or ponding operation is related to the leachate characteristics. To date, no instances of groundwater pollution by disposed ash have been reported. Related studies currently are in progress in which the availability of molybdenum, boron, and other trace elements to plants is being studied. The results of greenhouse studies have shown that application of fly ash to soils does increase the availability of boron, molybdenum, phosphorus, potassium, and zinc. Whether or not this constitutes a potential pollution problem regardless of the beneficial results to some plants is not yet conclusive.

The case study described in the report is the Widows Creek Steam Plant, located on the north shore of Guntersville Reservoir in Jackson County, Alabama. The TVA complex, which has a total generating capacity of 1968 Mw, consists of eight boilers fired by pulverized coal. Total consumption rate at full load is 677 metric tons per hour. Assuming an ash content of 17%, approximately 115 metric tons of ash are produced hourly; 75% of this is estimated to be fly ash.

Solid wastes generated at Widows Creek are disposed of by ponding. The original ash pond used for units 1-6, located inside a railroad loop, was filled and taken out of service when the existing pond was put into service in February of 1961. A portion of the first pond has been vegetated, while the other half is being used as a source of fly ash for mixing with cement.

The pond now in use is located northwest of the plant on the southern shore of Widows Creek Embayment. The 65 acre (26 hectare) area receives ash from all eight units.

A new disposal area is presently under construction. This project involves relocation of Widows Creek and its embayment. The site totals 93 hectares (230 acres) which will be divided into two areas, one for disposal of all ash from units 1-7 and the precipitator ash from unit 8 and the other for scrubber waste (sludge plus ash) from unit 8. The sludge and ash disposal areas will be separated by a divider dike. The pond bottom will be compacted by heavy equipment and, according to TVA design engineers, will become impervious due to early deposition of fly ash. The perimeter and divider dikes are being constructed of compacted earth removed from the pond's interior.

Operation of the new ash pond will be similar to that used for the existing pond and the effluent is likewise expected to be similar in composition. The spillway will discharge to an open channel along the southwest side leading directly to Guntersville Reservoir. Closed-loop operation of the scrubber is planned which will eliminate any discharge from the second waste area.

Monitoring results and environmental studies to date have not indicated any deleterious effects from ash pond discharge. Their disposal method effectively meets Alabama's effluent guidelines.

Coal ash disposal technology is relevant to scrubber sludge disposal in the following areas. The experience already gained by the utility industry in ash ponding and landfill management can be applied. Since ash will be ponded with sludge in many instances, it is likely that, from the standpoint of trace contaminants, the problems should be similar although data available at the present time are not complete enough to warrant any definite conclusions.

11.0 SCRUBBER SLUDGE

The sulfur compounds produced by flue gas desulfurization systems fall into two general categories: throwaway or saleable products. Lime/limestone scrubbing systems generate a throwaway sludge with little commercial value at the present time. Lime scrubbing processes ordinarily produce sludges containing $CaSO_3 \cdot \frac{1}{2}H_2O$, $Ca(OH)_2$, $CaSO_4 \cdot 2H_2O$ and $CaCO_3$; limestone sludges generally contain $CaSO_3 \cdot \frac{1}{2}H_2O$, $CaSO_4 \cdot 2H_2O$, and $CaCO_3$. For coal-fired installations where efficient particulate removal is not installed upstream of the wet lime/limestone absorber, such sludges can also contain large quantities of coal ash.

From data available to date, it has been found that the exact chemical composition of scrubber sludges varies widely from one system to another, and even within the same system. Therefore it is not possible to give an analysis which truly represents all systems.

The amount of sludge generated by a given plant is a function of the sulfur and ash content of the coal, the coal usage, the on-stream hours per year (load factor), the mole ratio of additive to SO_2, the SO_2 removal efficiency of the scrubbing system, the ratio of sulfite to sulfate in the sludge, and the percent moisture in the sludge. Table III lists values of these various sludge parameters for a hypothetical plant representing the National average expected between 1973 and 1980. These values represent a mix of Western and Eastern plants expected in 1980 based on the trends shown by present flue gas desulfurization system orders.

Table IV shows the quantities of ash and sludge produced per year by a 1,000 MW coal-fired generating station controlled by lime/limestone flue gas desulfurization systems.

TABLE III

TYPICAL SLUDGE PRODUCTION PARAMETERS

Sludge Production Parameters	National Average*
Coal:	
Sulfur Content	3.0%
Ash Content	12%
Plant:	
Load Factor	73%
Coal Usage	.4 kg/kw-hr
Scrubbing System:	
SO_2 Removal Efficiency	85%
Moisture in Sludge	50%
CaO/SO_2 (inlet) Mole Ratio	1.0
$CaCO_3/SO_2$ (inlet) Mole Ratio	1.2
Sulfite/Sulfate Mole Ratio	9:1

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*The values listed as the National average represent a mix of Western and Eastern plants expected in 1980 based on the trends shown by present flue gas desulfurization system orders.

TABLE IV

TYPICAL QUANTITIES OF ASH AND SLUDGE PRODUCED PER YEAR BY A 1000 MW COAL-FIRED GENERATING STATION CONTROLLED WITH LIME/LIMESTONE FLUE GAS DESULFURIZATION SYSTEMS

	Quantity Produced	Volume Required For Disposal
Coal Ash, dry	307,000 metric tons/year	315,000 cubic meters/year
Coal Ash, wet (80% solids)	384,000 metric tons/year	203,000 cubic meters/year
Limestone Sludge, dry*		
$CaSO_3 \cdot \frac{1}{2}H_2O$	264,000 metric tons/year	
$CaSO_4 \cdot 2H_2O$	39,000	
$CaCO_3$ Unreacted	99,000	
TOTAL	402,000 metric tons/year	N.A.
Limestone Sludge, wet (50% solids)	804,000 metric tons/year	551,000 cubic meters/year
Limestone Sludge, wet (with ash)	1,418,000 metric tons/year	971,000 cubic meters/year
Lime Sludge, dry*		
$CaSO_3 \cdot \frac{1}{2}H_2O$	264,000 metric tons/year	
$CaSO_4 \cdot 2H_2O$	39,000	
CaO Unreacted	43,000	
TOTAL	346,000 metric tons/year	N.A.
Lime Sludge, wet (50% solids)	692,000 metric tons/year	474,000 cubic meters/year
Lime Sludge, wet (with ash)	1,306,000 metric tons/year	895,000 cubic meters/year

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ASSUMPTIONS:

Coal:	3.0% S; 12% Ash
Plant:	6400 hr/yr; .4 Kg Coal/kw-hr
Scrubber:	85% SO_2 Removal
	1.0 CaO/SO_2(inlet) Mole Ratio
	1.2 $CaCO_3/SO_2$(inlet) Mole Ratio
Sludge:	Packing Volume 0.685 cubic meters/metric ton
Ash:	Packing Voluem 0.53 cubic meters/metric ton

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[*] Sulfite/sulfate ratio based on performance of Chemico scrubbing unit at Mitsui Aluminum Co., Japan.

These figures represent the National average sludge and ash production statistics.

Using the forecast demand for flue gas desulfurization given in the SOCTAP report (SU-031) and the national average annual sludge production rates per 1,000 MW of controlled generating capacity, the amount of wet ash containing sludge (50% moisture) that will have to be disposed of annually by 1980 is predicted to be 113 million metric tons. This value is based on the assumption that there will be 116,000 MW of generating capacity controlled by 1980 and that 75% of the control will be by lime/limestone scrubbing systems. The volume required for disposal of this amount of sludge would be approximately 77.4 million cubic meters.

Ponding and landfilling provide the major mechanisms of disposal for most solid waste products. In terms of land use and reclamation, these disposal mechanisms have many points of similarity for various industries. Land use for waste disposal may be esthetically objectionable. The wastes could provide varying degrees of surface and groundwater pollution depending on chemical composition, solubilities, and the location, design and operation of the disposal site. For land reclamation, most of the stable wastes will require only a cover material to support vegetation and prevent eventual erosion. However, some wastes are very resistant to dewatering and could reslurry in the pond or landfill. If this is shown to be true, it is likely that fixation will become a necessary practice.

Many of the solid wastes discussed in the preceding sections are disposed of by ponding. These include sewage sludge, phosphate slimes, taconite tailings, by-product gypsum, acid mine drainage sludge, and coal ash. Much of the technology already developed in handling these materials may be applicable to ponding of scrubber sludge. Those aspects which may be compared are settling characteristics of the waste, dimensional stability, pond construction, open-loop vs. closed-loop operation, and single-or multi-unit operation.

Potential hazards associated with contamination of surface and/or groundwaters by sulfur oxide sludges exist in the following areas:

- soluble toxic species (toxic meaning elements which can cause health problems even at very low concentrations),
- chemical oxygen demand due to sulfite,
- excessive total dissolved solids,
- excessive levels of specific species, e.g., sulfate and chloride, not generally thought of as toxic,
- excessive suspended solids.

The nature of the leachate expected from untreated sludge can be judged by analysis of liquors associated with scrubber samples, especially clarifier supernatant or scrubber recycle water in closed-loop operation. Since fly ash will be collected and/or disposed of together with the scrubber sludge in many cases, it is likely that many of the potentially leachable elements originate with the ash. Although ash ponds have been in operation for years, there has been little concern with environmental contamination either by high dissolved solids content or by trace element constituents of the pond waters. Both have recently been shown to be present in varying amounts in several ash pond samples. Likewise, this potential source of contamination has not been investigated for other wastes typically disposed of by ponding. This includes taconite tailings, phosphate slimes, AMD sludge, and phosphogypsum. This type of study, if it were available, would prove very useful in determining potential leachate problems due to scrubber sludge disposal.

Another potential source of water pollution from sludge ponds is overflow of supernatant. Disposal ponds have typically been operated with less than total recycle of pond liquor. Newer and more stringent regulations on waste water disposal will likely reduce the practice of overflowing excess liquor into lakes and streams. This will necessitate the use of closed loop (total recycle) operation for scrubber sludge disposal by ponding with treatment of any blowdown streams. Alternatively, blowdown streams might be disposed of via evaporation or disposal in the ocean. This sort of operation, combined with proper site selection, design, and lining of ponds could eliminate contamination of surface or groundwater by ponded scrubber sludge.

A second approach to the problem of disposal of waste solids generated by lime or limestone scrubbing systems is landfill. Currently less than 40% of existing or planned installations have adopted this alternative, while approximately 60% have included ponding facilities. Several solid wastes discussed in the previous sections are disposed of by landfilling; included in this category are municipal waste and coal ash. Landfill-related technologies are sometimes employed for sewage sludge and acid mine drainage sludge.

Characterization of lime/limestone scrubber sludge thus far has revealed a nature not readily applicable to untreated landfill disposal. The sludge does not settle or dewater readily, and the results of some experiments have indicated that once dried, the untreated material will reabsorb moisture to its original water content. This creates the unattractive possibility of the disposal site becoming a bog. A second aspect of untreated sludge is its leachate characteristics. For these reasons, chemical and physical fixation processes have been proposed and are now under investigation. The marketing agents for these fixation techniques claim that conversion to a physically and chemically stable landfill material is possible. Where leachate is a problem, leachate control systems developed for sanitary landfills may be applicable to scrubber sludge landfill sites.

The technology associated with disposal of waste scrubber sludges by landfill operations is currently in the development stage. There are three basic features requiring discussion to accurately describe the current state of knowledge regarding this disposal method: dewatering, fixation, and handling of sludge.

There are numerous techniques available for dewatering industrial wastes, many of which have been experimentally and industrially applied to sludges generated by lime or limestone scrubbing systems. Comparable studies have been conducted for dewatering other types of waste included in the present study which bear significance to scrubber sludge dewatering. Of special interest are phosphate slimes, gypsum from phosphoric acid manufacture, and acid mine drainage sludge.

Sludge fixation is the chemical and physical stabilization of sludge or sludge/fly ash mixtures. The intent of the processes is to convert the waste to a non-toxic, load-bearing material via chemical reaction and, in some cases, aggregate addition. Chemical fixation of scrubber sludge and related materials is currently under development by several commercial groups including Dravo Corporation, I. U. Conversion Systems, Inc., Chicago Fly Ash, and Chemfix Corporation. The ability of proposed fixation techniques to prevent rewatering and leaching from treated sludges is under investigation. Comparative evaluations of several of these processes are currently being planned or carried out in the laboratories of Aerospace Corporation under contract to EPA (Contract No. 68-02-1010) and in an independent study by Combustion Engineering, Inc.

Certain aspects of land reclamation following abandonment of a landfill site or dried up ponds used for scrubber sludges may lead to potential problems. These aspects may be assessed by examining the engineering, physical, and chemical natures of treated and untreated sludge. At the present time no attempts have been made to reclaim land committed to scrubber sludge disposal, although disposal sites for other solid wastes studied including municipal waste, coal refuse, phosphate slimes, taconite tailings, and coal ash have been successfully reclaimed. Extensive research in these areas is being carried out. The degree of reclamation possible varies with the characteristics of the waste.

Several other possible options are available for disposal of air pollution control system sludges although they are not under investigation to the same extent as landfill and ponding. These alternatives involve direct deposit of the waste below the surface in subsurface mines or utilization of the sludge to reclaim strip mine areas. Another possible solution is commercial utilization. Development in this area is currently in progress under both government sponsorship and private industry.

1.0 INTRODUCTION

Disposal of sulfur oxide sludges generated by flue gas desulfurization systems is currently under investigation by the Environmental Protection Agency and the utility industry. Radian Corporation, under contract to EPA, has been involved in the preparation of several documents dealing with this issue (Contract Nos. 68-02-1319, Task No. 1, "Information on the Status of Lime/Limestone Sludge Handling"; 68-02-0046, Task No. 12, "Utilization of Stack Gas Cleaning Equipment in Ohio"; and 68-01-2008, "Prepare a Technology Transfer Process Design Manual"). The reports generated from the last two programs listed are to be released shortly. During the course of those studies, the magnitude of the problem faced by the electric utility industry was estimated and briefly compared to similar waste disposal problems encountered in other areas. This document is an expansion of the comparison made at that time.

The purpose of the present investigation is to identify available technologies developed in other industries which may be applicable to scrubber sludge disposal. The general nature of the problem, disposal technologies, and environmental aspects for each of nine solid wastes destined for land disposal are presented in this document. The materials under study are listed in Table 1-1.

A case study approach was employed to obtain information related to specific problems encountered, ability of the technique to meet local environmental standards, and alternatives or modifications under consideration if the current method has proven inadequate. This type of approach was used in order to quantify each problem as much as possible.

The general problem descriptions and case studies are presented in Sections 2.0 through 10.0 below. Section

TABLE 1-1

SOLID WASTE MATERIALS

1. Municipal refuse
2. Sewage sludge
3. General ore wastes (rock waste only)
4. Culm piles
5. Phosphate slimes
6. Taconite tailings
7. Gypsum from phosphoric acid manufacture
8. Acid mine drainage sludge
9. Coal ash
10. Sludge generated by flue gas desulfurization systems

11.0 presents currently available data concerning the nature of scrubber sludge and a discussion of the applicability of disposal technologies developed by other industries to scrubber sludge disposal. The conclusions reached in this study are given in Section 12.0.

2.0 MUNICIPAL WASTE DISPOSAL

Disposal of the increasing tonnages of municipal wastes has traditionally been dealt with by landfilling or open dumping. Decreased land availability, higher land costs, and increasing public concern with environmental issues such as recycling and pollution, however, now demand alternate practices.

2.1 Nature of Municipal Waste

Municipal refuse can be accurately characterized by the term heterogeneous. Because of the numerous and varied sources, domestic, industrial and commercial, the content of typical refuse is difficult to predict. However, several attempts have been made to analyze wastes from specific facilities and to generalize from the results. One example from the literature is given in Table 2-1. This includes both a physical materials breakdown and an elemental analysis. A more detailed analysis of composite municipal waste was cited by Klass and Ghosh (KL-036); this is shown in Table 2-2.

Figures quantifying amounts of municipal solid waste generated annually tend to be in disagreement. Kasper reported annual urban refuse to be in excess of 123 million metric tons, while total U. S. refuse production (excluding industrial, mineral, and agricultural wastes) is approximately 168 million metric tons per year (KA-109). Data from a 1968 national survey indicated that 172 million metric tons of waste are collected annually by public and private agencies (HA-183). Kenahan, however, stated that the nation generates

TABLE 2-1

SAMPLE MUNICIPAL REFUSE COMPOSITION - U. S. EAST COAST (AFTER KAISER, 1967, AS CITED IN AP-014)

Physical	*Weight Percent*	*Rough Chemical*	*Weight Percent*
Cardboard	7	Moisture	28.0
Newspaper	14	Carbon	25.0
Miscellaneous paper	25	Hydrogen	3.3
Plastic film	2	Oxygen	21.1
Leather, molded plastics, rubber	2	Nitrogen	0.5
Garbage	12	Sulfur	0.1
Grass and dirt	10	Glass, ceramics, etc.	9.3
Textiles	3	Metals	7.2
Wood	7	Ash, other inerts	5.5
Glass, ceramics, stones	10		100.0
Metallics	8		
	100		

TABLE 2-2

COMPOSITION OF A COMPOSITE MUNICIPAL REFUSE (KAISER, AS CITED IN KL-036)

Percent	
23.38	Corrug. paper boxes
9.40	Newspaper
6.60	Magazine paper
5.57	Brown paper
2.75	Mail
2.06	Paper food cartons
1.98	Tissue paper
0.76	Plastic coated paper
0.76	Wax cartons
2.29	Vegetable food wastes
1.53	Citrus rinds and seeds
2.29	Meat scraps, cooked
2.29	Fried fats
2.29	Wood
2.29	Ripe tree leaves
1.53	Flower garden plants
1.53	Lawn grass, green
1.53	Evergreens
0.76	Plastics
0.76	Rags
0.38	Leather goods
0.38	Rubber composition
0.76	Paints and oils
0.76	Vacuum cleaner catch
1.53	Dirt
6.85	Metals
7.73	Glass, ceramics, ash
9.05	Adjusted moisture
100.00	

about 363 million metric tons of urban refuse each year; this included domestic, commercial, municipal, and industrial waste products (KE-101). Klass and Ghosh stated that urban refuse is produced at a rate of 5 pounds (~2.3 kilograms) per person per day, or ~0.8 metric ton annually per person (KL-036).

2.2 Disposal of Municipal Wastes

There are two phases of solid waste management: collection and disposal. The first of these is by far the most expensive; many estimates for this phase are in the range of 80% of the total cost (SO-054). It is the second phase, however, of interest in this investigation. In general, the following options are available for disposal of municipal wastes:

- sanitary landfill
- composting
- incineration with or without heat recovery
- pyrolysis
- resource recovery (i.e., recycling)

In the following discussion, each of these methods will be described. Information concerning procedures, economics, extent of use, and environmental aspects will be included.

2.2.1 Sanitary Landfill

Landfill operations still constitute the major form of municipal waste disposal. One source estimated that over 90% of the nation's solid waste is disposed of in this manner at ~12,000 individual sites (SO-054). The term sanitary landfill is defined as "a method of disposing of refuse on land without creating nuisances or hazards to public health or safety, by utilizing the principles of engineering to confine the refuse to the smallest practical area, to reduce it to the smallest practical volume and to cover it with a layer of earth at the conclusion of each day's operation, or at such more frequent intervals as may be necessary" (WE-095). This type of operation should not be confused with open dumping, a practice which involves none of the above considerations and which is becoming outlawed in an increasing number of communities.

Site selection is often hampered by land availability, especially in areas of extensive suburban growth. In fact, many are turning to other methods of disposal for this reason alone. The criteria that should be considered when selecting a site are:

- relationship to present and planned development
- potential water pollution
- availability of suitable cover material

- hauling routes and distances from production centers
- site development costs
- future use of site
- topography

The daily operation of a sanitary landfill must conform to local sanitary codes. The procedures described below are usually recommended. Dumping should be confined to well-defined areas in order to facilitate efficiency of spreading operations. The refuse normally is spread in layers not thicker than two feet to promote maximum compaction. The purpose of compaction is to conserve landfill space, minimize potential harborage for rodents and vermin, minimize subsidence, and reduce oxygen-containing voids which constitute a fire hazard. This is accomplished in conventional operations by specialized heavy equipment. Densities achieved by compaction may range from 300-600 kg/m^3 depending on the type of waste, moisture content, and equipment available. Several successive compacted layers may be placed until a lift 2.4-3.0 meters is achieved.

Placement of 15 cm of soil cover over the compacted waste is the next step. Daily covering is necessary to prevent insect and rodent infestation and to minimize fire potential. On completion of a fill area, an additional 0.6 meters of compacted cover should be laid. If multiple lift layers are planned, an intermediate cover layer 0.3 meter thick is recommended in place of the thicker cover layer for single lift fill. Vegetation of the final cover will provide dust control and prevent erosion.

Future use of the landfill site is becoming more of an important factor in planning and development. Several highly successful landfill golf courses are already in use (DU-053). Game preserves, parks, and even building sites are also potential future uses (RE-092, VI-015). Probably the most unique solution is development of a ski slope from layers of compacted refuse. This concept is being realized in at least two separate instances (ME-072, SK-017).

Potential environmental hazards associated with a sanitary landfill operation include groundwater contamination, gas generation, odor, subsidence, fire, and health hazards. Proper maintenance and operation of the landfill will effectively prevent fires, health hazards, and infestation by rats and insects. Filling and preventing cracks in the earth cover largely control odor; placement of activated carbon in the tops of gas vents is an added means of protection. Disinfectant application may also be used.

Groundwater contamination by landfill leachate has been the subject of numerous studies. A recent review by Heidman and Brunner (HE-063) summarizes published results of current research. Several experimental studies were designed to determine quantities, qualities, and movement of leachate (AN-066, AP-014, TR-031). In general, climate, temperature, age of landfill, composition, and original water content are chief factors of leachate characteristics. Initial leachate concentrations reported in one study were as follows (EM-006, as cited in EM-003):

BOD	20,000 mg/ℓ
COD	50,000 mg/ℓ
Fe	1,600 mg/ℓ
Cl	2,300 mg/ℓ

Prevention of leachate problems is achieved by careful design in accordance with topography and hydrogeology of the area. Recently, experimentation with sealing of landfills is being conducted; entrapped leachate is collected and treated, if necessary (RE-071). This concept may become important in scrubber sludge disposal if leachate is shown to pose a hazard.

2.2.2 Composting

Composting is the decomposition of organic matter to a relatively stable humus-like material by aerobic thermophilic action. This process is used as a disposal method for municipal solid waste. Its application is limited, however, by the relatively high costs involved and the heterogeneous nature of the waste. Although several in-depth studies of this method have been conducted, a discussion will not be included here because of its inapplicability to scrubber sludge disposal.

2.2.3 Incineration

Disposal of municipal waste by incineration is not a well-accepted disposal technique. In 1968 there were an estimated 300 municipal incinerators in operation taking care of ~8% of the nation's waste; this figure dropped to only 193 in 1972 (HA-193). Pollution problems, operational difficulties, and high costs are blamed. Although economic offsets such as resource recovery and marketing of generated steam are often cited as advantages for this method, experiences have been that it is difficult to find markets for the steam. In addition, recovery of metal value from incinerator residue is still not feasible. Finally, although incineration does reduce the bulk of municipal waste by more than half, the residue must still be ultimately disposed of, usually in a landfill.

Incinerators generate three forms of potential pollutants: solid residue (ash); stack gas; aqueous effluent. Achinger and Daniels reported the results of an evaluation of seven incinerators from which data were collected describing refuse, solid waste residue, fly ash, and waste water (AC-002). They concluded that solid waste was reduced by more than 94%, thus little residue was produced. Particulate emissions exceeded most air quality criteria, while aqueous effluents were found to be contaminated but no treatment was being applied. The following water streams were analyzed: incoming water, quench water, scrubber water, and plant effluent. Detailed results are available in the literature.

In another study, the sulfur balance for incinerators was determined (KA-110). Typical municipal refuse was found to contain 0.10-0.15% sulfur. The authors concluded that during combustion, most of the sulfur remained fixed in the ash which contains alkaline oxides. Only minor amounts were released in the stack gas. Observed emissions from four facilities ranged from 1 to 100 ppm.

Particulate emissions from municipal incinerators must be controlled; usually this is accomplished by electrostatic precipitators or mechanical collectors. Another approach, however, is controlled air incineration to reduce the problem (CR-053). The location of the air supply is also regulated. In this way it is possible to prevent entrainment of particulates from the refuse bed. This incinerator design can frequently meet emission standards of 0.23 grams of particulate matter per cubic meter at 50% excess air when burning general refuse without the aid of gas washing devices.

2.2.4 Pyrolysis

Pyrolysis is related to incineration in that both are thermal degradation processes. However, pyrolysis takes place in the absence of air, produces a different residue and a different off-gas. It is currently still in the developmental stages, but it is considered a promising replacement for the trouble-plagued incineration method. The advantages of this process over conventional incineration include (HA-183, LI-061):

- inherently lower pollution potential
- potential energy recovery
- greater flexibility in that type of product output and recovery system can easily be altered

- lower estimated operating costs
- relatively low land requirement

The process itself is an endothermic reaction which converts organic materials into three main component streams. The gas is composed of hydrogen, methane, carbon monoxide, and carbon dioxide. This fuel is readily combustible in conventional furnaces with conventional burners although the Btu content is lower than that of fossil fuels. The liquid stream consists of organic chemicals such as acetic acid, acetone, and methanol at room temperature. The char produced is basically carbon plus any inerts such as glass, metal, or rock. The final product mix depends on the heating rate and ultimate temperature attained.

One of the advantages of this process is its estimated lower cost. Part of the reason for this is the low pollution potential involved, thus possibly eliminating the need for expensive pollution control equipment. This aspect needs further investigation, however.

2.2.5 Resource Recovery

This approach is perhaps the most widely publicized method for disposal of municipal wastes. The Council on Environmental Quality has completed a program in which the basic feasibility of resource recovery was examined (FR-070). A second part of their study involved evaluation of twelve specific recovery processes (MI-081). Energy recovery was discussed in previous sections of this report (incineration). Fuel recovery is one feature of pyrolysis processes. One type of materials recovery, composting, was also mentioned previously.

Materials recovery processes are designed to remove paper, ferrous and nonferrous metals, and glass from refuse. All four are recovered in most processes. Paper can be separated from mixed waste by both wet and dry processes. Metal recovery processes are under development. Ferrous metal separation is based on magnetic separations and is fairly well established technology. Air classification or flotation is the usual basis for glass separation.

Environmental aspects will of course vary with the type of recovery system employed. The Aluminum Association's system, described in reference (SO-056), has installed air and water controls in all phases of plant operation. Air pollution control equipment is provided for the incinerators, pyrolysis unit, and general plant ventilation. This includes electrostatic precipitators for particulate collection and a packed tower scrubber for sulfur compounds, chlorides, and odor. The scrubbing liquor contains sodium carbonate, sodium hydroxide, or potassium permanganate. A venturi scrubber is used to remove kiln emissions from the pyrolysis unit. Other equipment includes baghouse and fabric filter collectors. For water treatment, provision has been made for installation of a 650-gpm water treatment facility if needed.

The extent to which reclamation is currently being practiced is quite low. Salvage of metal cans from municipal waste is minimal. Approximately 2% of "tin" cans are reused in the beneficiation of copper ore, while recycling of aluminum cans amounts to less than 5% of annual production. The glass content of municipal refuse has increased with greater use of nonreturnable bottles; collection at reclamation centers accounts for only 2-3% of annual production. Plastic reclamation is prevented at the present time by lack of technology for its separation (HE-061).

2.3 Case Studies of Municipal Waste Disposal

The only one of the five disposal technologies described above that is being considered for scrubber sludge disposal at the present time is landfill. While many aspects of sanitary landfilling of municipal refuse are in no way related to the present investigation, leachate generation, migration, and collection are topics of environmental concern for both types of waste. The following case studies were selected on the basis of special emphasis given to one or more of these areas.

2.3.1 Sonoma County Central Solid Waste Disposal Site

The Central Sonoma County Landfill is the largest of six county disposal sites, handling 60% of the waste generated in the area, or 650 metric tons of refuse daily (CO-166, CO-167). The site was opened in July of 1971 and by the time of completion, estimated at the year 2002, will fill a canyon of approximately 100 acres (40 hectares) to a depth of 60 meters. Design features of interest to the present study is the leachate collection recycle system which involves migration to the surface and subsequent evaporation or recycling through the refuse. The disposal site is located in a large canyon in the southwestern portion of the county, approximately 70 kilometers north of San Francisco.

The area is underlain primarily by marine sediments of the Franciscan Formation, consisting of sandy clayey shale with interbedded sandstones and silicic chert beds. Above this formation on the canyon floor are relatively thin deposits of poorly consolidated sediments of younger Merced Formation. These rocks generally consist of gravelly sandstones with interbeds of sandy clay and silt. Permeabilities of representative clay soil samples were less than one foot (0.3 meter) per year.

Groundwater in the disposal area is very limited, especially in the Franciscan sedimentary rocks. These marginal supplies of poor to fair quality water do not constitute a protectable resource. Sediments of the Merced Formation contain groundwater of moderate to high quality in the more pervious strata contained in beds of sand, gravels, and occasionally permeable volcanic rock. Test wells drilled in the canyon bottom area revealed the presence of an aquifer ranging in thickness from 0.6 to 3 meters occurring from 4.5 to 7.5 meters below the surface. In addition to the subsurface water, at least one perennial and two intermittent springs exist in the canyon at the upper end of the disposal site. Although production capacity from wells in this aquifer were marginal, hydraulic continuity between this aquifer and major production aquifers to the south established a definite need to prevent indirect pollution of the latter by refuse leachate.

In addition to construction of access roads, preparation of the disposal site involved erecting a clay cutoff barrier across the bottom of the canyon, extending through the aquifer-containing Merced Formation into the Franciscan Formation. This barrier provides a physical separation between the canyon groundwater and any downstream aquifers. A leachate collection system was engineered by which the leachate is brought to the surface where it is evaporated or recycled through the refuse. Surface drainage is intercepted and diverted around the active portion of the site.

The daily operation of the landfill is carried out by refuse compaction in place by compactors and bulldozers. A new elevating scraper now on order will soon provide the capability of a full sanitary landfill operation.

The major bulk of refuse is domestic and light industry with limited agricultural dumping allowed. Some sorting is carried out prior to compaction. This consists of removal of white goods and large metal pieces; recycling of these two types of refuse is presently the only reclamation effort planned.

The monitoring program employed at the Central Sonoma County Landfill, as outlined by the regulatory agency, the California Regional Water Quality Control Board, consists of the procedures described in Table 2-3 (CA-139). Three sampling points are monitored: (1) the main landfill sump (leachate recycle); (2) collection point near the main cutoff barrier prior to discharge across the boundary (surface drainage water); and (3) sand drainage blanket located downgradient from the cutoff barrier. Monitoring reports are submitted to the Regional Board on a monthly basis. The local waste discharge requirements as presented by the California Regional Water Quality Control Board, North Coast Region, do not cite specific limits which cannot be exceeded although "neither the treatment nor discharge of waste shall cause a nuisance or pollution". The County officials feel, however, that their present procedures provide compliance with all existing water quality control standards.

TABLE 2-3

WATER MONITORING PROGRAM AT CENTRAL SONOMA COUNTY LANDFILL

Sample Point	Constituent	Units	Type of Sample	Frequency
1	COD	mg/l	Grab	Monthly
	TDS	mg/l	Grab	Monthly
	Specific Conductance	Micromhos/cm	Grab	Monthly
	Mean Daily Flow	GPD	Grab	Daily
	pH	---	Grab	Monthly
2	COD	mg/l	Grab	Monthly
	TDS	mg/l	Grab	Monthly
	Specific Conductance	Micromhos/cm	Grab	Monthly
	pH	---	Grab	Monthly
3	COD	mg/l	Grab	Semiannually*
	TDS	mg/l	Grab	Semiannually
	Specific Conductance	Micromhos/cm	Grab	Semiannually
	Iron	mg/l	Grab	Semiannually
	pH	---	Grab	Semiannually

---

*Samples should be collected during the months of January and July.

2.3.2 Sonoma County Refuse Test Cells

Adjacent to the full-scale landfill described in the previous case study, a demonstration project is underway to investigate stabilization of refuse. The study is funded principally by EPA under Demonstration Grant No. G06-EC-00351 of the Office of Solid Waste Management Programs. Partial funding of the three-year project is provided by the County of Sonoma.

The purpose of the investigation is two-fold:

(1) To investigate the stabilization of refuse in a sanitary landfill by analyzing leachate, gas, temperature, and settlement parameters.

(2) To determine the effect on refuse stabilization of applying excess water, septic tank pumpings, and recycled leachate to a sanitary landfill under various operational modes.

The general geological and hydrological features of the disposal site were presented in the preceding case study. An extensive survey was made of the test area which is located midway up the central canyon in a relatively flat portion of the valley, just east of the main drainage channel. A small tributary channel passes through the test area, with three test cells to the north and two to the south. Little groundwater was found in the preconstruction survey within twelve feet of the ground surface in the test area. The native soils in their natural state were considered generally satisfactory for leachate retention. Occasional areas of more pervious water-bearing soils were expected, however, in the excavations. These areas were over-excavated two feet, then lined with an impervious clay material. Additional details of construction of the cell, including the leachate collection system, are available in the Second Annual Report of the Sonoma County Refuse Stabilization Study. The cell dimensions are approximately 15 by 15 meters at the base, and 21 by 21 meters at ground level. Each cell is 2.5 meters deep.

Test procedures included sorting and compaction of refuse. After placement, the refuse was covered with 0.6 meters of stockpiled sandy clay material from cell excavation. Some of the test cells also contained a one-foot impermeable layer between the refuse and cover material. Each of the five test cells was subjected to different conditions of liquid recycling; these are summarized in Table 2-4. The monitoring schedule observed from the period February 1972 through May 1973 is shown in Tables 2-5 and 2-6 for leachate and gas, respectively. Slightly different schedules were employed during the initial phase of the study and since May 1973. These details are available in their Second Annual Report. Although the project has not yet been completed, preliminary results as reported in the Second Annual Report are summarized below for each test cell.

Cell A serves as the control against which the other four cells are compared in terms of effectiveness of the operation procedures on refuse stabilization. Monitoring was initiated in December 1971. However, the first significant quantity of leachate from the control cell was not obtained until October 1972 when the first winter rainfall occurred. Cracks in the soil cover permitted considerable access of storm water until the clay cover swelled, sealing the cracks. Both the volume and values for compositional parameters of the leachate prior to November 1972 were very low in comparison with the other cells, perhaps indicating that the initial leachate samples

TABLE 2-4

LIQUID CONDITIONING AND PURPOSE OF CELLS

Cell Designation	Initial		Operation		Purpose of Cell
	Liquid Conditioning	Liquid Used	Daily Liquid Application gal/day	Liquid Used	
A	None	None	None	None	Control Cell
B	Field Capacity*	Water	None	None	To determine the effect of high initial water content on refuse stabilization.
C	None	None	700± ** (200-1000)	Water	To determine the effect of continuous water through flow on leachate character.
D	None	None	1000± ** (500-1000)	Recirculated Leachate	To determine the effect of continuous leachate recirculation on leachate character.
E	Field Capacity*	Septic Tank Pumpings	None	None	To determine the effect of high initial moisture content, using septic tank pumpings, on refuse stabilization.

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*Field capacity is the condition when a sufficient quantity of fluid has been added to the refuse to cause a significant volume of leachate to be produced from the cell.

**Range of variation in daily application of fluid.

TABLE 2-5

SUMMARY SAMPLING SCHEDULE
FREQUENCY OF ANALYSIS FOR VARIOUS PARAMETERS
COMMENCING FEBRUARY 15, 1972

	Leachate		Groundwater
Parameter	Cells A, B & E	Cells C & D	Wells 1 thru 4 A & E Subdrain Water Supply Cell C
K	6-week intervals	monthly	quarterly
Na	6-week intervals	monthly	quarterly
Ca	6-week intervals	semi-monthly	quarterly
Mg	6-week intervals	semi-monthly	quarterly
Hg	6-week intervals	monthly	quarterly
Pb	6-week intervals	monthly	quarterly
Zn	6-week intervals	monthly	quarterly
Cu	6-week intervals	monthly	quarterly
Cl	6-week intervals	semi-monthly	quarterly
PCB	---	quarterly	semi-annually
pH	6-week intervals	semi-monthly	monthly
Alkalinity	6-week intervals	semi-monthly	quarterly
COD	6-week intervals	semi-monthly	quarterly
BOD	6-week intervals	semi-monthly	semi-annually
TDS	6-week intervals	semi-monthly	quarterly
TSS	6-week intervals	semi-monthly	quarterly
Settleable Solids	---	quarterly	
Nitrogen			
Ammonia	6-week intervals	semi-monthly	semi-annually
Organic N	6-week intervals	semi-monthly	---
Nitrate N	6-week intervals	semi-monthly	semi-annually
Sulphate	quarterly	quarterly	quarterly
Tot. Phosphate	6-week intervals	semi-monthly	---
DO	6-week intervals	semi-monthly	monthly
Color	6-week intervals	semi-monthly	---
Volatile Acids	6-week intervals	monthly	---
Fecal Coliform	quarterly	quarterly	semi-annually
Elect. Conductivity	6-week intervals	semi-monthly	monthly
Fecal Streptococci	semi-annualy	semi-monthly	semi-annually

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[*] Initial test of Cell A leachate will include all parameters listed in December 1971 schedule in addition to those listed above.

TABLE 2-6

SUMMARY SAMPLING SCHEDULE

Frequency of Gas Analysis

Commencing February 15, 1972

Cell Location	Sampling Frequency
Cell A - Bottom	Quarterly
A - Middle	Monthly
A - Top	Quarterly
Cell B - Bottom	Quarterly
B - Middle	Monthly
B - Top	Quarterly
Cell C - Bottom	Quarterly
C - Middle	Monthly
C - Top	Quarterly
Cell D - Bottom	*
D - Middle	*
D - Top	Monthly
Cell E - Bottom	Quarterly
E - Middle	Monthly
E - Top	Quarterly

---

*No gas samples can be withdrawn from these probes due to fluid interference. Attempts in January 1972 to remove fluids encountered in these probes were unsuccessful. Attempts will be made periodically to withdraw samples.

were condensate. The following parameters showed marked increase after November 1972: EC (electrical conductivity), TDS, Ca^{2+}, Mg^{2+}, SO_4, volatile acids, and alkalinity. The low pH of 5 was indicative of a high partial pressure of CO_2. This in turn meant that biodegradation of organic material was taking place. Both phosphorus and nitrogen levels were slightly lower than those from other test cells, however, some degree of biological activity was evident.

Trace metals data for all five cells are presented in Tables 2-7 through 2-9. In cell A cadmium never exceeded the analytical detection limit. However, since the detection limit was above the 1962 U. S. Public Health Service Drinking Water Standard (0.01 ppm), no conclusion could be drawn concerning the potential hazard of this element. Copper was found to be present in the 0.1-0.2 ppm range which is an order of magnitude below the USPHS standard (1.0 ppm). Zinc, lead, and mercury, however, were consistently detected in amounts greater than or near the USPHS standards of 5 ppm, 50 ppb, and 5 ppb, respectively. Final analysis of their potential hazards must consider possible interactions between leachate and soil and potential removal mechanisms such as ion exchange, absorption, adsorption, and precipitation.

Cell B represented a landfill having reached field capacity via the addition of 155,000 liters of water prior to placement of the cover material. No further additional management procedures were employed on this cell. As in Cell A, the first winter rains resulted in swelling and subsequent sealing of the cover material, thus cutting off infiltration through cracks. Leachate data generated from the onset of the test until the winter rains in October 1972 were scattered and generally reflected leachate composition ranges reported in the literature.

TABLE 2-7

TRACE METAL CONCENTRATIONS IN LEACHATE
CELLS A, B & E

CELL A	ELEMENT - mg/l				
Date	Cu	Zn	Cd	Hg	Pb
2-15-72	ND	2.1	ND	0.0006	ND
9-7-72	ND	0.23	ND	0.0065	0.16
10-11-72	0.16	0.58	ND	0.0035	0.12
11-21-72	0.15	9.0	ND	0.013	0.44
4-10-73	0.22	3.0	ND	ND	1.81
CELL B					
1-31-72	3.6	140.0	ND	0.006	3.0
10-24-72	0.29	62.0	0.19	0.0035	0.95
3-13-73	0.18	10.8	ND	0.0044	0.33
CELL E					
2-15-72	ND	ND	--	0.0005	ND
10-24-72	0.12	1.67	0.09	0.0145	0.60
1-23-73	0.10	41.0	ND	0.0112	0.60
3-13-73	0.19	5.6	ND	0.0044	0.45
4-24-73	0.32	64.0	0.05	ND	0.21
6-5-73	0.10	58.0	0.05	--	0.42

ND - Not Detected

-- - No Analysis Made

TABLE 2-8

TRACE METAL CONCENTRATIONS IN LEACHATE

CELL C

Date	ELEMENT - mg/l Cu	Zn	Cd	Hg	Pb
3-2-72	0.6	42.0	ND	0.0014	ND
4-11-72	ND	30.0	ND	0.0016	ND
5-9-72	ND	30.0	ND	0.015	ND
6-6-72	0.15	22.0	0.1	0.0102	0.8
7-11-72	0.15	13.0	ND	0.0065	ND
7-25-72	0.18	10.0	ND	--	0.1
8-8-72	0.13	9.5	ND	0.018	0.2
9-7-72	0.07	7.5	ND	0.06	0.22
10-11-72	0.08	6.5	ND	0.0065	0.15
10-24-72	0.06	7.5	0.05	--	0.35
11-8-72	0.11	8.5	0.06	0.035	0.15
11-21-72	0.1	8.0	0.04	--	0.17
2-6-73	0.06	4.6	ND	0.0166	ND
2-27-73	0.06	4.5	ND	0.0123	ND
3-13-73	0.05	4.3	ND	0.0007	0.1
3-27-73	0.06	2.8	ND	--	--
4-10-73	0.08	3.5	0.05	0.0034	0.1
4-24-73	0.05	3.8	0.05	0.0078	0.1
5-15-73	0.04	2.5	0.05	0.0018	ND
6-26-73	0.02	0.6	<0.05	0.0002	Tr.

ND - Not Detected

-- - No Analysis Made

TABLE 2-9

TRACE METAL CONCENTRATIONS IN LEACHATE

CELL D

	ELEMENT - mg/l				
Date	Cu	Zn	Cd	Hg	Pb
1-18-72	0.4	95.0	0.1	0.003	2.0
3-2-72	ND	40.0	ND	0.0058	ND
4-11-72	ND	40.0	ND	0.0028	1.0
5-9-72	ND	30.0	ND	0.0066	ND
6-6-72	0.1	30.0	0.13	0.0052	0.5
7-11-72	0.15	28.0	ND	0.009	0.18
7-25-72	0.16	28.0	ND	--	0.35
8-8-72	0.14	--	ND	0.012	0.64
9-7-72	0.15	21.5	ND	0.064	0.36
10-11-72	0.25	29.5	ND	0.0055	0.59
10-24-72	0.1	28.5	0.16	--	0.47
11-8-72	0.35	27.5	0.09	0.0022	0.32
11-21-72	0.32	25.0	0.04	--	0.37
1-10-73	0.29	21.0	ND	0.0086	0.43
1-23-73	0.08	22.5	ND	0.0108	0.40
2-6-73	0.11	17.8	ND	0.016	0.23
2-27-73	0.12	17.6	ND	0.0123	0.46
3-13-73	0.09	16.9	ND	0.0047	0.24
3-27-73	0.12	17.5	ND	0.0016	--
4-10-73	0.08	14.0	0.05	0.0008	0.1
4-24-73	0.06	15.0	0.05	0.003	0.5
5-15-73	0.04	12.0	0.05	ND	ND
6-26-73	0.08	8.5	<0.05	0	0.31

ND - Not Detected

-- - No Analysis Made

Data for the time period from October 1972 on could be explained in terms of volume flow-through and biological activity within the cell. In general, anaerobic biodegradation continues, but no significant activity of methanogenic organisms has been observed. CO_2 content remains high, corresponding to low pH, high alkalinity and volatile acids. Sulfate content has not yet begun to decrease; thus apparently cell conditions promoting sulfate reduction to sulfide have not yet developed. However, the most significant aspect is the discernible decreasing trend for most parameters (with the exception of pH and P) during this period. This dilution mechanism is especially evident for TDS and EC. The trace metals data for Cell B are similar to those from Cell A. The only distinct difference was the presence of a high cadmium level on one occasion (0.19 ppm on 24 October 1972).

Cell C was subject to continuous flow-through conditions, with 3,000 liters of water applied daily. This resulted in an overall flushing action as evidenced by decreasing concentrations of all parameters except pH with time. The response of cell temperature to atmospheric conditions as a function of depth was different in this cell. Whereas Cells A and B displayed temperature profiles which varied strongly as a function of depth, the test conditions of Cell C tended to stabilize the profile through the depth of the cell.

Vigorous biological activity was indicated by data on gas composition, BOD, COD and volatile acids. Higher methane concentrations were evidence of strong methanogenic organism activity. Increasing proportions of ammonia nitrogen and corresponding decreasing organic nitrogen concentrations reflected vigorous biodegradation. Other biological parameters were also discussed in the original report. Most of the inorganic parameters including Na, K, Ca, Mg, Cl, TDS, and EC showed a rather smooth trend toward lower concentrations with time. The first six months of data which show high electrolyte concentrations reflect the flushing out of readily solubilized inorganic material, leaving behind those requiring biodegradation. The only trend noticed in trace metal leachate data was decreasing zinc concentration. Again zinc, lead, and mercury were all present at levels higher than the USPHS standards.

The settling rate for this cell was much greater than that observed for either Cells A, B, or E. The data indicate an accelerated rate of compaction compared to the control cell.

The most significant effect observed with continuous recycling of leachate in Cell D was the leveling trends of leachate compositions even though volume of recycled leachate varied by of a factor of 10 during the test due to rainfall and other factors. This was especially true for Na, K, Ca, and Mg during the period October 1972 to March 1973. In addition, the thermal response of the upper layers was damped by continuous recycling.

Biological activity was characterized as active anaerobic. Strong reducing conditions within the cell were reflected in the relative absence of nitrate, apparent sulfate reduction, and continually high values for soluble reduced iron. Substantial amounts of organic matter accumulating in the leachate is shown by the stable BOD and COD measurement.

Heavy metals showed a tendency to build up in the recycled leachate. Cadmium was the only one of five measured which did not exhibit this pattern, although this may have been due to the analytical technique employed. The pH of the liquor was ~5. Additional results are included in the Second Annual Report.

Cell E has been seeded with septic tank pumpings to provide microbial seed to accelerate biological degradation processes. Since this cell was designed to test parameters not applicable to scrubber sludge disposal, the results are not discussed here.

Parameters used as indicators to determine extent of groundwater contamination included Cl, Na, K, Ca, Mg, SO_4, alkalinity, TDS, and EC. To date, the results indicate that the earth cells are effective in preventing water pollution from leachate.

3.0 SEWAGE SLUDGE DISPOSAL

The bulk of solids present in sewage is separated as a sludgeous material during primary treatment. This sludge may either be disposed of directly or in combination with sludges resulting from secondary treatment processes. A disposal method extensively used in coastal areas has been to barge sewage sludge to sea for discharge to the ocean's depths. Biological investigations have revealed, however, that ocean biota is adversely affected by this practice (SA-116). Consequently, in October, 1970, the Council on Environmental Quality released a policy recommending phasing out ocean dumping of sludge. For this policy to be enforced, however, feasible alternatives must be available. Thus, in 1971 EPA established two task forces to investigate possible alternatives. One group looked at all potential disposal techniques; the second group examined incineration in depth.

3.1 Nature of Sewage Sludge

A preliminary document describing the composition and environmental impact of sewage sludge has been published by Salotto and Farrell as an appendix to the EPA report on sewage sludge incineration by the EPA Task Force (EN-084). Much of the following material is a summary of the contents of that document; the information is augmented in some instances with additional published results.

The object of primary treatment is the removal of the majority of suspended solids from sewage by a settling process. The resulting waste is referred to as primary sludge. Secondary treatment usually involves oxidation of soluble organics by the action of microorganisms. During this process, the population of microorganisms increases and a portion must be wasted, generally as a dilute sludge. Sludge is designated as "raw" until it has been subject to stabilization processes such as heat treatment or digestion.

The exact nature of sewage sludge depends on the source of the waste and the treatment received. The water content of sludge can range between 85 and 99.9%. Primary sludge usually consists of 65-75% combustible matter, with most of the inorganics remaining in the ash residue. After digestion, the volatile matter drops to ∿50% with a corresponding increase in proportion of ash. Most of the ash occurs as particulate mineral matter (sand and clay). Table 3-1 illustrates the expected ranges of major components of various types of sewage sludges. Digested sludge contains nitrogen, phosphorus, and to some extent, potassium, the three basic components of fertilizer. The liquid phase contains approximately one-half the nitrogen and smaller proportions of phosphorus, while the solids contain the bulk of the phosphorus and the remaining nitrogen (DA-078).

Elemental analyses of 31 elements are presented in Table 3-2. The major elements found are calcium, magnesium, sodium, potassium, aluminum, iron, sulfur, and silicon. In another study, metal contents of sludges from various plants were analyzed to show typical variations. The authors commented that it was not possible to predict relative amounts of metals on the basis of the sludge's origin being either predominantly industrial or predominantly domestic. These data are shown in Table 3-3.

The EPA Task Force has estimated the amount of domestic sewage sludge produced in the United States (EN-084). For every million gallons of sewage, approximately one ton of sludge production is estimated. Assuming that

TABLE 3-1

MAJOR COMPONENTS OF SLUDGE* (EN-084)

Constituent	Types of Sludge				
	Raw Primary	Digested	Waste Activated	Filter Cake Raw	Filter Cake Digested
Volatile Matter	60-80	45-60	62-75	55-75	40-60
Ash	20-40	40-45	25-38	25-45	40-60
Insoluble Ash	17-35	35-50	22-30	15-30	30-45
Greases & Fats	7-35	3-17	5-12	5-30	2-15
Protein	22-28	16-21	32-41	20-25	14-30
NH_4NO_3	1-3.5	1-4	4-7	1.3	1.3-1.6
P_2O_5	1-1.5	0.5-3.7	3-4	1.4	0.5-3.5
K_2O		0-4	0.86		
SiO_2		20-22	12		
Fe		5.4	7.1		
Cellulose	10-13	10-13	7.8	8-10	8-12

*All data are presented on a dry basis.

TABLE 3-2

SUMMARY OF MAJOR AND MINOR ELEMENTS IN SLUDGE (EN-084)

(mg/g dried sludge)

Element	Primary Sludge	Activated Sludge	Digested Sludge
Aluminum	5.1	10.0	17.9
Antimony	n.a.*	n.a.	0.9
Arsenic	< 1.2	1.2	n.a.
Barium	2.2	1.2	1.4
Beryllium	0.0025	0.0035	0.0025
Boron	0.10	0.070	0.046
Cadmium	< 0.19	0.35	0.26
Calcium	n.a.	13.0	33.5
Chromium	2.0	4.3	2.3
Cobalt	0.22	0.002	n.a.
Copper	2.0	1.1	1.6
Gallium	0.05	0.05	0.05
Iron	16.1	40.5	30.6
Lead	1.0	1.5	1.9
Magnesium	10.6	7.0	7.5
Manganese	0.78	0.31	0.98
Mercury	0.005	0.02	n.a.
Molybdenum	0.36	0.20	0.25
Nickel	0.52	0.38	0.38
Phosphorus	3.8	19.9	12.8
Potassium	n.a.	4.2	2.8
Silicon	n.a.	40.0	162
Silver	0.24	0.15	0.20
Sodium	4.0	4.4	6.2
Strontium	0.13	0.16	0.26
Sulfur	n.a.	10.1	12.3
Tin	0.95	0.50	0.60
Titanium	14.8	11.8	14.2
Vanadium	2.1	0.7	5.2
Zinc	6.9	3.3	4.0
Zirconium	1.7	10.0	2.0

*n.a. - not available.

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Vanadium	2.1	0.7	5.2
Zinc	6.9	3.3	4.0
Zirconium	1.7	10.0	2.0

*n.a. - not available.

TABLE 3-3

CONCENTRATION OF METALS IN SLUDGES (EN-084)

(mg/g)

	Tahoe	Dayton	Little Miami Cincinnati	Mill Creek Cincinnati	Lorton Va.	Indianapolis Plant 1	Barst
	7/15/71	8/25/71	8/20/71	8/20/71	8/5/71	8/23/71	7/20/
Ag, Silver	0.27	0.36	0.03	n.d.	n.d.	n.d.	0.05
Al, Aluminum	13.2	12.5	8.8	32.2	4.4	5.2	16.2
Ba, Barium	3.0	3.0	0.7	n.d.	0.7	1.3	1.5
Be, Beryllium	n.d.[1]	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cd, Cadmium	0.18	0.8	n.d.	n.d.	0.17	0.24	0.58
Co, Cobalt	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cr, Chromium	1.0	5.9	1.7	1.8	0.4	2.6	0.5
Cu, Copper	1.3	6.0	2.3	1.6	0.9	2.0	1.7
Fe, Iron	8.7	20.4	16.0	13.2	27.4	15.3	10.6
Hg, Mercury	4.5*	n.a.[2]	n.a.	n.a.	3.0*	n.a.	5.5*
Mn, Manganese	0.6	1.1	1.2	0.6	0.5	0.6	0.18
Ni, Nickel	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Pb, Lead	2.8	6.9	2.0	2.7	1.1	2.8	0.8
Sr, Strontium	0.51	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
V, Vanadium	n.d.	n.d.	n.d.	1.6	n.d.	n.d.	2.1
Zn, Zinc	1.6	8.4	7.8	4.7	0.4	1.2	1.4

* - micrograms/g
1 - n.d.: not detected
2 - n.a.: not analyzed

Analytical determinations on these sludges were carried out by J. Kopp, Analytical Quality Control Laboratory, Robert A. Taft Water Research Center.

the per capita sewage production is 400 liters (100 gallons) per day, 10,000 people will produce 4 million liters (one million gallons) of sewage and consequently 0.9 metric ton (one ton) (dry basis) of sludge per day. If thoroughly digested, the sludge mass will be reduced to 450 kg (1,000 pounds) per day.

On a nationwide basis, municipal sewage sludge production is estimated to increase from ∿265 million liters (70 million gallons) per day in 1960 to ∿640 million liters (170 million gallons) per day in 1980 (CA-124). Another source estimates that 55,000,000 metric tons of sewage sludge (0.1-15% solids) will be produced in 1980 (SC-164).

3.2 Pre-Disposal Treatment and Handling

In this subsection the procedures sometimes employed in the pre-disposal treatment of sewage sludge will be discussed briefly. These include dewatering and transport.

3.2.1 Sewage Sludge Dewatering

Volume reduction of sludges prior to actual dewatering and ultimate disposal is often practiced to reduce costs. Volume reduction, or sludge concentration, is defined as the reduction in moisture content in order to decrease sludge volume while still maintaining its fluid properties. Maximum solids content typically desired is 10% since denser sludges are viscous and difficult to pump. For example, waste activated sludges usually contain 0.5-1.0% solids. Concentration to 3 or 4% can be significant. Raw primary sludges, on the other hand, often are already 5-6% solids; a separate concentration step prior to dewatering or final disposal is less practical here.

The conventional gravity sludge concentrator is equipped with a slowly-turning rake moving over the bottom. This effects breaking up of the floc bridging, thus allowing increased particle settling. One example of practical experience in this area has been described by Alford (AL-039).

Vacuum filters are the most common mechanical dewatering device used (CL-039). Most large treatment plants which dewater their sludges employ these in their process. Typical filtration rates achievable for activated and well-digested primary sludges vary from 12 to 54 kg/m^2 /hour (2.5-11 lb./sq. ft./hr.), respectively. Filter cake solids contain 60-85% moisture, depending on the nature of the conditioned sludge. Chemical flocculation usually is necessary to adapt the sludge to this technique. Factors that determine the amount of chemical needed are sludge concentration, type of sludge, and alkalinity. Commonly used flocculants include ferric chloride and lime or polyelectrolytes.

Another mechanical dewatering method is centrifugation, applied to solid-liquid separations in waste treatment plants fairly recently. Several types of centrifuges are available; details are available in the literature (AL-032, CL-039, KE-082). Practical experience has been described by Alford (AL-039). Efficiency of this method depends basically on the relative densities of the solid and liquid phases. As a result, the type of sewage treatment greatly affects the results as illustrated in Table 3-4. Heat conditioning of the solids is reported to increase the dewatering capability of this technique (AL-032).

TABLE 3-4

DEWATERING OF WASTE SLUDGES BY CENTRIFUGING (AL-032)

Location	Type	Feed, % TS	Overflow, % TSS	Cake % TS	Recovery, % TS	Chemicals, $/ton DS
Calif.	RP	3.83	0.49	35.0	88.2	0
Mich.	DP	8.8	1.44	30.0	88.2	0
Conn.	R(P&AS)	3.61	0.06	20.0	98.2	6.40
N.J.	R(P&B)	9.57	0.05	22.9	99.2	7.95
Conn.	D(P&AS)	3.5	0.30	20.0	93.0	15.00
Calif.	D(P&B)	2.79	0.44	22.0	95.0	16.00
Texas	AS	2.19	0.55	19.6	97.9	12.40

TS = total solids, TSS = total suspended solids, DS = dissolved solids, R = raw, D = digested, P = primary, B = biofilter, AS = waste-activated sludge

Heat can also be used as a drying technique as well as a conditioning treatment for sewage sludge (WE-078). Thermal drying is accomplished by the introduction of hot gases to rapidly remove moisture from the solids. Some of the advantages of this method include reduction of harmful pathogenic microorganisms, odor destruction, and volume reduction.

3.2.2 Sewage Sludge Handling

The transport of digested sludges by pipeline over long distances has been growing in importance since 1964 when the idea of piping sludge slurries to strip-mined areas for land reclamation projects was proposed to the U.S. Public Health Service. The more conventional function of piping sludge is short-distance, in-plant transport. Pipelines are also employed in ocean disposal projects.

The flow characteristics of digested sludges change from Newtonian below ∿5% solids to non-Newtonian above 5% solids. This feature is of fundamental importance in economic design of pipeline systems. Below this cutoff, sludge transport economics are comparable to water transport costs with respect to fluid friction and power requirements (RA-075). Costs will increase in roughly inverse proportion to the solids concentration from zero to 5%. Although there are few technical problems in handling low-solids sludges, economic penalties are experienced because of the greater volumes (excess water). For solids concentrations greater than 5%, use of small diameter pipes is impractical due to the friction head losses. Even in larger pipes, turbulence in the region of accepted economic velocities is reported. Table 3-5 presents pipe sizes that can carry digested sludge slurries from various population levels and related amounts of dry materials conveyed.

TABLE 3-5

PIPELINE SYSTEM DESIGN DATA (RA-075)

Population Served	Nominal Pipe Size (inches)[1]		Approximate Annual Dry Sludge Solids (metric tons)
100,000	1-1.5	design challenge	1,400
500,000	2.5-3.5		7,000
1,000,000	4		14,000
2,000,000	5		29,000
3,000,000	6		42,000
4,000,000	8		58,000

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[1] 1 inch = 2.54 cm.

Thompson et al. have studied the economics of regional waste transport and disposal systems (TH-041). Total pipeline transport costs ranged from $1.76 per metric ton ($1.60 per ton) for a 40-km (25-mile), 820 metric ton (900 ton) per day system to $22 per metric ton ($20 per ton) for a 160-km (100-mile), 91 metric ton (100 ton) per day system. These costs include both capital and operating expenses and are based on a 3.5% solids digested slurry. The economics of this type of system are very sensitive to scale; increasing the size from 91 to 820 metric tons per day reduces total transport costs from $22 to $5.50 per metric ton.

Comparisons with other modes of transport were also reported (TH-041). Truck or rail may be used for land disposal, while barge and tanker are in use for ocean disposal. The economics of each case must be examined in order to determine which handling method is the most feasible. Several general conclusions were drawn, however. For example, in cases of low tonnages or short distances, trucking is more economical for land disposal systems. In one case, costs for barge transport of sewage sludge were reported to have decreased from $25.25 per metric ton in 1961 to $9.72 per metric ton in 1972 (Guarino as cited in DI-053). Improved unloading techniques, greater quantities, and longer contract periods accounted for this reduction. The original literature should be consulted for further details.

3.3 Disposal Techniques

The disposal technology for sewage sludge having the greatest potential application to scrubber sludge disposal is reclamation of devasted land. The most well-known example is the disposal system used by Chicago since 1971 which consists of barging 6800 metric tons of digested sludge at 3-5% solids 300 kilometers from the treatment plant to southern Illinois (HI-069, DA-078, PR-057, VA-078). The sludge is spray-irrigated onto the fields after temporary lagooning to reduce harmful pathogenic microorganism population. Further details are presented in Section 3.4 in the case study.

Other ultimate disposal technologies for sewage sludge are more common, but are limited in their potential application to the scrubber sludge problem. Ocean dumping, although a major means of sludge disposal in the past, especially in coastal areas, is being phased out because of possible environmental hazards (EN-084).

Another alternative fairly recently to come under development is composting. This process is the aerated microbial decomposition of organic matter during which the temperature of the pile increases to 140-170°F due to thermophilic action of microorganisms (US-082). This process begins within 24 hours after placement of the sludge; as soon as the action starts, odors do not form. The heat evolution drives off the moisture, and usually within two weeks a dry odorless compost material is ready for distribution. Daily turning of the piles and initial mixing with previously composted material is recommended for maximum efficiency. A hectare (10-acre) demonstration project for this disposal technique was proposed early in 1973. 100-150 tons (dry weight) of sludge per day from the Washington, D. C., area will be transported to the Agricultural Research Center in Beltsville, Maryland, spread in windrows, mixed with other bulk materials, and turned by machine once a day. Approximate yields of 75 tons (dry weight) of compost per day are expected. Possible environmental hazards will be studied as well as optimization of the process itself.

In 1971 a Task Force was established by EPA to study the feasibility of incineration as a sewage sludge disposal technique to replace ocean dumping (EN-084). They evaluated two types of furnaces: multiple-hearth (2 existing plants) and fluidized bed furnace (1 existing plant). All were equipped with particulate scrubbing devices. Special emphasis was placed on air and water pollution potential. The results of the study indicated that incineration is capable of achieving low emissions of common pollutants although lead was found in high concentrations in the stack particulate. The original literature should be consulted for further details. The general conclusions were that a well-designed and -operated incinerator can meet stringent existing particulate emission control regulation.

Pyrolysis of sewage sludge is also available as a disposal technique. When powdered dried sludge is heated in the absence of air, a considerable reduction of mass occurs due to the production of volatile gases, and the residue is black containing carbon.

Other methods of sewage sludge disposal include permanent lagooning and an experimental moisture-reducing process which converts treated sewage into a nutritious animal food supplement (SU-037). Lagooning has been in use for many years, but is currently being phased out in favor of schemes that require less land and are more appealing to the public. Potential pollution aspects require further investigation.

3.4 Case Study - The Prairie Plan

The utilization of municipal sewage sludge in reclamation of devastated mining areas is currently being tested on a large scale by the Metropolitan Sanitary District of Greater Chicago in conjunction with the Fulton County, Illinois, Board of Supervisors. This cooperative venture began with the purchase of 2800 hectares (7000 acres) of strip-mined land as a disposal site for Chicago's sewage sludge. The district serves a residential population of 5.5 million people as well as an industrial population equivalent to another 4.5 million. On the order of 4.9 billion liters (1.3 billion gallons) of waste water are processed daily, yielding ~910 dry metric tons of solids daily (PR-057). Approximately 50% of this quantity is currently being barged to the site by the Prairie Plan.

The land purchased is located ~320 km (200 miles) south of Chicago in Fulton County, Illinois. Basically, it is a tract of gently sloping land consisting of spoil bank soil, with soil textural classifications ranging from silty clay loam to clay loam. This particular spoil is neither stony nor acidic, having a surface pH of 7.1-7.6 (HI-069). The tract is located on the upper reaches of the Spoon River watershed, virtually a self-contained basin with a creek ultimately discharging to the Illinois River.

This land is well suited to sewage sludge application. Soil analyses have shown that Fulton County spoil will supply 361-401 kg/hectare of available potassium, 10 kg/hectare available phosphorus, greater than 140 kg/hectare of reserve phosphorus, and a very low nitrogen value. In contrast, sewage sludge is low in potassium, but high in available phosphorus and nitrogen as well as humus content. The following levels were reported:

potassium	3-5 kg/dry metric ton
nitrogen	25-30 kg/dry metric ton
phosphorus	30-35 kg/dry metric ton, ∿80% readily available

The trace element content of sewage sludge is commonly quite high. A typical analysis of Chicago's sludge is given in Table 3-6. Hinesby, Jones, and Sosewitz predicted that application of sludge on strip-mined lands could be accomplished without encountering trace element problems (i.e., accumulation of toxic levels in the soil) because the high metal content of the spoil itself "insures some irreversible adsorption of the metals and therefore decreases absolute amounts available to plants" (HI-069).

In the summer of 1971, the first load of sludge was barged down the Illinois River to Fulton County. Currently, about 6810 wet metric tons per day (370 dry metric tons per day) of the 4% solids sludge are being transported. Eight barges, each having a capacity of 1450-2800 wet metric tons, are used to make the 36-hour round trip. The transport cost is the major item in the reclamation project; estimated cost is $37 per dry metric ton, or $0.12/dry metric ton/kilometer ($0.18/dry ton/mile). A pipeline transport system is now under consideration; this is expected to reduce the transport cost to $0.03/dry metric ton/kilometer ($0.05/dry ton/mile) (PR-057), which would greatly improve the overall economics of the project, recently quoted at $55/dry metric ton (RE-089).

At Liverpool, the sludge is pumped from the barges to one of three holding ponds 17 kilometers away. This is accomplished with a 300 horsepower pump which can accommodate sludges up to 10% solids (DA-078). Maximum

TABLE 3-6

AVERAGE COMPOSITION OF MSDGC LAGOONED DIGESTED SLUDGE (HI-069)

Total Element	Concentration Kg/dry metric ton of Solid
N	54.0
P	65.0
Cd	0.95
Cr	8.4
Cu	4.6
Fe	95.4
Pb	3.0
Ni	0.85
Zn	14.9
Mn	0.5
Ca	52.5
Mg	14.7
K	8.0
Na	3.1

flow through the 508 mm underground pipeline is 0.2 m^3/sec (3000 gpm). The holding basins have a total capacity of 6 million cubic meters, 1.5-2.3 million cubic meters each. They are built on tight clay soil and are lined with a 60 cm (24-inch) thick packed clay blanket (PR-057).

These holding basins serve several purposes. Their main function is to hold the sludge until the appropriate time for application, depending on the season, rainfall, soil conditions, etc. The retention time will be a minimum of 30 days and probably more on the order of six months in order to allow time for the sludge to age. This will destroy most pathogenic microorganisms that survive the digestion process; remaining resistant forms will not present an environmental hazard if soil erosion and sediment transport are minimized (HI-069). Odor formation will also be prevented by the lagooning and aging process. Another purpose is to reduce the nitrogen content of the sludge, which is the limiting factor in determining sludge application rates. Mechanical aerators are being tested in one holding basin to reduce the ammonia-nitrogen content by stirring the sludge to the surface where evaporation can take place.

In 1971, the first tract of land was prepared for cultivation. This involved leveling to a maximum 5% grade to prevent rapid runoff of sludge. In addition, earthen berms were constructed around the edges of the fields to direct runoff to collecting basins situated in depressions resulting from the mining operations.

In 1972, 320 hectares were planted with corn. Sludge application was not made until the plants were 20 cm tall, at which time an application rate of 56 metric tons per hectare was made several times to approximately one-half the area while the other half received no fertilization (PR-057). The treated section yielded 131 bushels per hectare (53 bushels per acre) compared to only 32 bushels per hectare (13 bushels per acre) for the control section. It has been calculated that 168 dry metric tons per hectare (75 tons/acre) can be applied the first time without exceeding the nitrogen fixation capacity of the spoil (i.e., no nitrogen buildup). Decreasing amounts would be applied in subsequent years until a rate of 18 metric tons per year is reached. One source suggested a loading rate of 450 dry metric tons of lagooned sludge per hectare over a four-year period (HI-069). This would result in the top surface foot of reclaimed spoil having a 4-5% humus content to a depth of 0.3 meter at the end of that period.

The technique used for applying the sludge is spray irrigation. The settled sludge (∿10% solids) is removed from the bottom of the lagoon by a floating dredge and pumped to an on-shore holding tank (DA-078). From here it is pumped to a field distribution system composed of modular units, each consisting of pumps, an above-ground header system, and a "big gun" spray vehicle. In the fields, 203 mm pipe brings the "liquid fertilizer" to six self-propelled irrigation units, each with a spraying capacity of 13-63 liters per second. The sludge is sprayed outward within a 52-meter radius of the vehicle which is drawn by a 180-meter cable winch through the fields at 30-213 cm/min (PR-057). Three or four passes per year should be sufficient to apply the required volume of sludge. In most cases, applications will be made before planting and after harvesting.

A natural filtering system will be relied upon to insure that water reaching surrounding streams is of high quality. As the sludge filters down through the crop roots, bacteria convert sludge nutrients to forms usable by the plant. Remaining liquor continues to pass downward until an impervious stratum is reached, at which point horizontal movement occurs. Farm fields will be surrounded by hedge rows. Any nutrients seeping out of the field will be taken up by their extensive root systems. As mentioned previously, monitored field detention basins will collect all surface runoff. If not polluted, the water will be released to a nearby stream. However, if quality is poor, then the entire contents will be recycled through the field. Additional protection will be provided by lines of hedges and trees along banks and streams. All streams entering and leaving the 7000-acre tract will be monitored. Additional monitoring stations including reservoirs, springs, and wells will be checked monthly for changes in water quality.

Although no results are yet available from the water monitoring program at the large scale site, a small demonstration study to investigate leachate from sewage sludge application to highly acidic spoil was conducted in 1966. Sponsors were the Metropolitan Sanitary District of Greater Chicago and the U.S. Forest Service. Four 0.05-hectare plots were treated with Chicago sewage sludge at the following rates (LE-094):

Plot I	303.7 dry metric ton per hectare
Plot II	178.2 dry metric ton per hectare
Plot III	77.8 dry metric ton per hectare
Control	0.0

In each plot a strip two meters wide was tilled to mix the sludge with the spoil and seeded in April of 1971 with tall fescue and weeping love grass. By May, all plantings had germinated and were growing except for those on the control plot. A direct relationship existed between the rate of sludge application and the observed growth rates.

Over a 15-month period, subsurface drainage was collected and analyzed. The results are shown in Table 3-7. Initially from November 1970 through September 1971 a sharp decrease in metals concentration in the leachate was observed. These levels rose slightly from October 1971 through January 1972. The results were explained as follows: during the first winter season, the levels decreased because of neutralization of plot acidity and because the sludge acted as a high capacity cation exchanger. Then, during the growing season evapotranspiration and low rainfall further decreased acid production, resulting in further decreased metal solubility. During the second dormant season, the reverse occurred; heavy rainfall and subsequent high acid production resulted in increased metal solubility.

In comparing relative effects of sewage sludge application rates on leachate composition, it was observed that the heaviest treatment rate resulted in the greatest reduction in acidity, Al, and Cu before and after treatment. On all three treated plots, acidity, Al, Fe, and Mn levels were reduced by at least 50% over the course of the test. Although the leachate results obtained from the control plot varied so widely that it was not possible to make meaningful comparisons between treated and untreated plots, it was generally observed that the average concentrations of acidity, Fe, Al, and SO_4 on the treated plots were always less than on the control.

TABLE 3-7

AVERAGE CONCENTRATIONS OF METALS IN SUBSURFACE RUNOFF FROM SLUDGE TREATED PLOTS (LE-094)

	Treatment (mt per hectare)						
	303.7		178.2		77.8		0
	Before	After	Before	After	Before	After	Average
Element	(milligrams per liter)						
Al	1,240	402	395	138	440	346	548
Cd	1.14	1.92	0.31	1.18	0.70	1.13	0.66
Cr	3.5	4.8	1.3	1.6	2.3	3.4	2.1
Cu	11.6	7.5	3.8	3.3	4.0	3.6	4.5
Fe	3,700	1.260	1.280	320	1,000	822	1,620
Mn	70	30	51	17	71	42	36
Pb	0.33	0.23	0.16	0.18	0.42	0.18	0.22
SO_4	11,000	7,740	8,400	3,730	7,100	6,770	7,980
Zn	24.4	36.4	8.1	24.8	14.1	26.0	13.3
Acidity	22,940	8.900	7.310	3,320	7,040	5,900	9,770

While the above results tend to indicate the positive environmental effects of sewage sludge application, some negative effects were also observed. The levels of several toxic metals including Cd, Cr, Zn, and in one case Pb were found to increase over the test period. It was concluded that the observed increase in heavy metals concentration may have been due to insufficient application rate; i.e., sludge, which is the source of many of the heavy metals, was applied at a rate which did not effectively neutralize the plot acidity, thereby promoting dissolution of metals added with the sludge.

Disposal of sewage sludge by application to acid mine spoil thus far appears to be a promising approach to this problem. Results indicate that crop yields are markedly improved, that acid stream pollution can be effectively reduced, and that the devastated land can be returned to productive use. Future results will provide more detailed insight into potential contamination of ground water by trace metals released from the sewage sludge itself.

4.0 GENERAL ORE WASTES

The mining and milling industry annually handles over 3.6 billion metric tons (4 billion tons) of materials, better than half of which is waste. These wastes can be classified in three categories: waste rock, tailings, and mine water. Waste rock, which includes overburden, is the waste developed during exploration, development, and mining of ore deposits; this is the material of interest in this study. Both metallic and nonmetallic minerals will be included with the exception of coal and other fuels which are excluded from this discussion because of the unique impact and magnitude of the acid mine drainage problem associated with the resultant waste.

4.1 Nature of the Waste

Waste rock occurs as discreet pieces which may be as large as 2 meters in diameter. It may or may not be mineralized depending on the particular geology of the site. If minerals are present, however, their levels are below the point where it would be economically feasible to recover them. Exact chemical composition cannot be given in a broad study of this type because the nature of the wastes are so much a function of each individual case. The waste does not contain chemical additives, however, with the possible exception of traces of explosives, fuel oil, gasoline, lubricants, or other substances lost during the mining operation (DU-052).

The Bureau of Mines reports that in 1970 the output of ore and waste at metal and nonmetal mines totaled 3.7 billion metric tons (4.087 billion tons). Wastes for that year totaled 1.3 billion metric tons (1.410 billion tons) (US-079). Table 4-1 presents a breakdown of materials handled crude ore vs. waste) on the basis of mineral mined and type of mining operation for 1970. Table 4-2 compares amounts of crude ore and wastes handled by various states. Data presented in Tables 4-1 which was partially estimated was not included in Table 4-2; this accounts for the seeming discrepancies in the total tonnages.

4.2 Disposal Methods

Disposal practices for rock mining wastes, overburden and tunnel rock, are not very sophisticated. There are three options normally available. Of 3.0 billion metric tons (3.3 billion tons) of overburden produced by the total surface mining industry in 1966, much was simply redeposited in the mined-out areas (BO-090). Approximately 10% was used in the construction of dams for tailings and ponds. The third alternative involved just heaping the waste in piles near the mine; these piles are referred to as waste banks.

The environmental effects associated with these disposal practices include loss of stability in the piles, reclamation, and erosion. The biggest problem thus far is the aesthetic issue. Contamination of groundwater by leachate has not been studied. Duncan reported that the soluble components of waste rock are a minor source of trouble, the only problem being with heavy metals. If the dump is properly sited and managed, however, any metal dissolution can be effectively prevented from leaving the immediate area (DU-052).

TABLE 4-1

MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES, BY COMMODITIES, IN 1970 (US-079)

(Thousand short tons)

Commodity	Surface			Underground			All mines		
	Crude ore	Waste	Total	Crude ore	Waste	Total	Crude ore	Waste	Total
METALS									
Bauxite	[1] 3,144	[1] 5,417	[1] 8,561	W	W	W	3,144	5,417	8,561
Copper	232,558	606,321	838,879	27,390	883	28,273	259,948	607,204	867,152
Gold:									
Lode	1,964	8,342	10,306	2,175	280	2,455	4,139	8,622	12,761
Placer	1,504	895	2,399	---------	---------	---------	1,504	895	2,399
Iron ore	221,187	206,451	427,638	14,794	2,234	17,028	235,981	208,685	444,666
Lead	6	5	11	10,816	803	11,619	10,822	808	11,630
Mercury	269	1,773	2,042	173	24	197	442	1,797	2,239
Molybdenum	5,360	48,533	53,893	16,701	107	16,808	22,061	48,640	70,701
Nickel	1,138	600	1,738	---------	---------	---------	1,138	600	1,738
Silver	25	135	160	737	190	927	762	325	1,087
Titanium: Ilmenite	23,698	2,946	26,644	---------	---------	---------	23,698	2,946	26,644
Tungsten	20	---------	20	711	14	725	731	14	745
Uranium	2,746	84,750	87,496	3,643	1,061	4,704	6,389	85,811	92,200
Zinc	379	244	623	9,629	1,650	11,279	10,008	1,894	11,902
Other [2]	4,513	2,047	6,560	16	7	23	4,529	2,054	6,583
Total metals	499,000	968,000	1,467,000	87,000	7,000	94,000	586,000	975,000	1,561,000
NONMETALS									
Abrasives [3]	217	7	224	40	---------	40	257	7	264
Asbestos	1,595	1,669	3,264	21	---------	21	1,616	1,669	3,285
Barite	3,886	1,660	5,546	107	2	109	3,993	1,662	5,655
Boron minerals	12,350	16,871	29,221	---------	---------	---------	12,350	16,871	29,221
Clays	53,668	[e] 47,000	100,668	1,096	[e] 16	1,112	54,764	47,016	101,780
Diatomite	611	2,515	3,126	---------	---------	---------	611	2,515	3,126
Feldspar	1,553	559	2,112	7	---------	7	1,560	559	2,119
Fluorspar	31	33	64	776	5	781	807	38	845
Gypsum	7,161	15,307	22,468	2,258	132	2,390	9,419	15,439	24,858
Mica	341	419	760	---------	---------	---------	341	419	760
Perlite	636	---------	636	4	---------	4	640		640
Phosphate rock	124,951	265,128	390,079	415	4	419	125,366	265,132	390,498
Potassium salts	---------	---------	---------	16,604	933	17,537	16,604	933	17,537
Pumice	3,230	88	3,318	---------	---------	---------	3,230	88	3,318
Salt	5,898	2	5,900	15,284	280	15,564	21,182	282	21,464
Sand and gravel	943,941	---------	943,941	---------	---------	---------	943,941	---------	943,941
Sodium carbonate (natural)	---------	---------	---------	4,221	2,673	6,894	4,221	2,673	6,894
Stone:									
Crushed and broken	833,964	[e] 70,000	903,964	38,693	[e] 270	38,963	872,657	70,270	942,927
Dimension	[e] 5,400	[e] 1,900	[e] 7,300	32	---------	32	5,432	1,900	7,332
Sulfur: Frasch	7,932	---------	7,932	---------	---------	---------	7,932	---------	7,932
Talc, soapstone, pyrophyllite	565	981	1,546	463	16	479	1,028	997	2,025
Vermiculite	1,445	4,108	5,553	---------	---------	---------	1,445	4,108	5,553
Other [4]	2,078	1,753	3,831	72	---------	72	2,150	1,753	3,903
Total nonmetals	2,011,000	431,000	2,442,000	80,000	4,000	84,000	2,091,000	435,000	2,526,000
Grand total	2,510,000	1,399,000	3,909,000	167,000	11,000	178,000	2,677,000	1,410,000	4,087,000

[e] Estimated. W Withheld to avoid disclosing individual company confidential data.

[1] Includes underground; Bureau of Mines not at liberty to publish separately.

[2] Antimony, beryllium, magnesium, manganese, platinum-group metals, rare-earth metals, and vanadium.

[3] Emery, garnet, and tripoli.

[4] Aplite, graphite, greensand marl, iron oxide pigments (crude), kyanite, lithium minerals, magnesite, olivine, pyrites, and wollastonite.

TABLE 4-2

MATERIAL HANDLED AT SURFACE AND UNDERGROUND MINES (INCLUDING SAND AND GRAVEL AND STONE), BY STATES, IN 1970 (US-079)

(Thousand short tons)

State	Surface			Underground			All mines		
	Crude ore	Waste	Total	Crude ore	Waste	Total	Crude ore	Waste	Total
Alabama	30,672	23,921	54,593	2,070	207	2,277	32,742	24,128	56,870
Alaska	35,753	1,251	37,004	5	3	8	35,758	1,254	37,012
Arizona	157,550	350,273	507,823	16,947	625	17,572	174,497	350,898	525,395
Arkansas	32,209	6,247	38,456	830	2	832	33,039	6,249	39,288
California	218,834	67,205	286,039	2,187	179	2,366	221,021	67,384	288,405
Colorado	26,818	133	26,951	18,708	894	19,602	45,526	1,027	46,553
Connecticut	15,476	40	15,516	---------	---------	---------	15,476	40	15,516
Florida	183,039	220,944	403,983	---------	---------	---------	183,039	220,944	403,983
Georgia	39,708	49	39,757	1,008	---------	1,008	40,716	49	40,765
Idaho	20,914	16,675	37,589	1,546	276	1,822	22,460	16,951	39,411
Illinois	99,534	---------	99,534	2,764	---------	2,764	102,298	---------	102,298
Indiana	50,464	---------	50,464	866	35	901	51,330	35	51,365
Iowa	46,716	5,966	52,682	1,964	---------	1,964	48,680	5,966	54,646
Kansas	27,887	---------	27,887	2,818	56	2,874	30,705	56	30,761
Kentucky	33,914	1	33,915	5,373	1	5,374	39,287	2	39,289
Louisiana	32,595	---------	32,595	6,277	20	6,297	38,872	20	38,892
Maine	14,232	1,039	15,271	32	---------	32	14,264	1,039	15,303
Maryland	29,980	---------	29,980	126	---------	126	30,106	---------	30,106
Massachusetts	26,345	---------	26,345	---------	---------	---------	26,345	---------	26,345
Michigan	128,834	16,062	144,896	12,715	244	12,959	141,549	16,306	157,855
Minnesota	208,007	106,631	314,638	---------	---------	---------	208,007	106,631	314,638
Mississippi	13,051	---------	13,051	---------	---------	---------	13,051	---------	13,051
Missouri	50,218	1,162	51,380	21,860	1,081	22,941	72,078	2,243	74,321
Montana	46,453	43,291	89,744	730	180	910	47,183	43,471	90,654
Nebraska	16,499	---------	16,499	37	---------	37	16,536	---------	16,536
Nevada	32,725	64,057	96,782	78	36	114	32,803	64,093	96,896
New Hampshire	6,966	---------	6,966	---------	---------	---------	6,966	---------	6,966
New Jersey	33,895	234	34,129	169	1	170	34,064	235	34,299
New Mexico	41,074	122,357	163,431	19,316	1,423	20,739	60,390	123,780	184,170
New York	82,035	4,016	86,051	6,302	202	6,504	88,337	4,218	92,555
North Carolina	51,728	15,021	66,749	100	---------	100	51,828	15,021	66,849
North Dakota	8,280	---------	8,280	---------	---------	---------	8,280	---------	8,280
Ohio	91,077	---------	91,077	6,087	100	6,187	97,164	100	97,264
Oklahoma	24,799	6,411	31,210	992	---------	992	25,791	6,411	32,202
Oregon	33,318	609	33,927	53	1	54	33,371	610	33,981
Pennsylvania	84,501	975	85,476	6,946	928	7,874	91,447	1,903	93,350
Rhode Island	2,808	---------	2,808	---------	---------	---------	2,808	---------	2,808
South Carolina	18,007	263	18,270	---------	---------	---------	18,007	263	18,270
South Dakota	18,865	4,649	23,514	1,994	146	2,140	20,859	4,795	25,654
Tennessee	43,334	8,862	52,196	11,852	705	12,557	55,186	9,567	64,753
Texas	92,297	11,909	104,206	628	5	633	92,925	11,914	104,839
Utah	61,848	101,558	163,406	1,630	402	2,032	63,478	101,960	165,438
Vermont	6,548	621	7,169	191	6	197	6,739	627	7,366
Virginia	46,951	35	46,986	2,997	628	3,625	49,948	663	50,611
Washington	39,712	1,217	40,929	299	160	459	40,011	1,377	41,388
West Virginia	12,178	---------	12,178	2,380	---------	2,380	14,558	---------	14,558
Wisconsin	61,098	3,692	64,790	837	42	879	61,935	3,734	65,669
Wyoming	18,220	72,159	90,379	5,347	2,713	8,060	23,567	74,872	98,439
Other States [2]	8,792	22	8,814	---------	---------	---------	8,792	22	8,814
Total	2,507,000	1,279,000	3,786,000	167,000	11,000	178,000	2,674,000	1,290,000	3,964,000

[1] Partially estimated data in table 1 not included in State totals.
[2] Delaware and Hawaii.

Because of the lack of any highly developed technology for disposal of this waste, no case study will be presented.

5.0 CULM PILES

The coal mining and preparation industry is faced with several types of solid waste disposal problems. The mining operations yield a waste consisting of rock and other impurities removed during the development and working of the mine. The quantities generated by underground mining are relatively minor and are generally considered to have little environmental impact. This type of waste becomes a major problem in the strip mining industry, however, where vast amounts of material covering the coal bed are removed and placed in "spoil banks" adjacent to the strip. Reclamation of these banks is currently under extensive investigation.

The solid waste of interest in this section is the refuse generated by the coal preparation processes. To produce a marketable coal, the raw coal must be crushed, sized, separated from impurities, and washed. Coarse coal is usually recovered in a dense-medium process. The coal is floated off in a suspension of finely divided solids in water, in aqueous solutions of inorganic salts (e.g., calcium chloride), or in an organic liquor. A flotation process is employed to beneficiate the fine coal, often using kerosene plus pine oil as the flotation agent. These operations are carried out in plants in the vicinity of the mine. Two types of waste products result: coarse refuse (>1 mm) and fines (<1 mm) (MC-096). The fines are typically disposed of by slurrying to a settling pond. The coarse refuse is often a major disposal problem, especially if the raw coal is of low grade. Between 5 and 30% of the coal can be deposited with the coarse refuse, depending on the efficiency of the separation process. Most modern techniques seldom leave more than 5% saleable coal in the refuse, while older culm piles often contain up to 30%, and in some cases, up to 75% recoverable coal. This washer plant waste is commonly accumulated in dumps called "culm piles", sometimes referred to as gob piles, coal refuse banks, or breaker refuse. The waste contained in older culm piles usually was sorted from the coal by hand. These piles may be as high as 200 meters (700 feet) and over 1.6 kilometers (one mile) long.

5.1 Nature of the Waste

The composition of coal refuse piles depends on the geological characteristics of the coal seam and overburden, efficiency of the beneficiation process, and whether or not the preparation plant waste is disposed of separately from mining wastes and settling pond solids.

The culm material generally consists of waste coal, slate, bone, carbonaceous and pyritic shales, and clay associated with the coal seam. Thick-seamed coal tends to have a high proportion of bone, whereas thin-seamed coal wastes will be low in bone and high in clay shales. Processing plant wastes from strip-mined coal are characterized by significant amounts of fine sand, silt, and clay. Davies reported that typical concentration ranges for major components were: 15-40% waste coal (except when settling pond solids are deposited with culm, resulting in up to 60% coal content); 30-70% carbonaceous and clayey shale; and 10% sandstone (DA-075). A typical chemical and physical analysis of culm material and coal fines is given in Table 2-1.

The types and proportions of individual components affect the physical and engineering properties of the bank as well as the chemical features. Shale, for example, is very susceptible to weathering, resulting in fragments that are resistant to compaction. Sandstone, on the other hand, weathers into slabs and irregularly shaped plates, presenting little problem in the bank. Clay either enters the bank as

TABLE 5-1

CHEMICAL AND PHYSICAL CHARACTERIZATION OF SELECTED PREPARATION PLANT WASTES (US-055)

Sample description	Culm bank (gob) material	Coal fines [1]
Moisture (percent)	0.6	0.9
Ash (percent)	62.6	15.4
Sulfur (percent)	3.17	1.56
Carbon (percent)	23.32	78.31
Volatile matter (percent)	15.5	25.2
Loss on ignition	37.2	83.8
Btu	4, 710	12, 320
	Ash Analysis	
SiO_2 (percent)	57.60	51.00
Al_2O_3 (percent)	28.10	28.10
Fe_2O_3 (percent)	8.74	11.20
TiO_2 (percent)	1.31	1.22
CaO (percent)	.59	.89
MgO (percent)	.64	.63
Na_2O (percent)	.53	.44
K_2O (percent)	2.16	1.80
	Fusion Properties	
Initial deformation temperature (°F)	1, 830	1, 620
Softening temperature (spherical) (°F)	2, 900+	2, 730
Softening temperature (hemispherical) (°F)	2, 900+	2. 750
Fluid temperature (°F)	2, 900+	2. 770
	Physical Properties	
Water solubility (percent)	1.4	.88
Water absorption (percent)	2.7	28.4
Bulk density (lb/ft^3)	69.0	46.5
Compacted bulk density (lb/ft^3)	78.0	53.0

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[1] High carbon containing fines resulting from coal cleaning operations, often impounded in slurry form behind the bank.

an integral quantity (i.e., not well mixed with other components) or ultimately winds up in the settling pond. The overall bulk density of culm material generally ranges from 1300-1800 kg/m^3 (80-110 lb./ft.^{3}) although the extremes may be 800-2,000 kg/m^3(50-125 lb./ft.^{3}).

The particle size range of coal refuse depends on the period during which the mining and processing took place. Modern banks contain greater proportions of finer particles; predominant sizes range from barley [0.24-0.48 cm (3/32"-3/16")] to egg [6.19-8.25 cm (2 7/16"-3 1/4")] (MA-222, US-079). Older banks have the following particle size distribution (DA-075):

30-60%	silt or smaller size
30-50%	coarser than silt up to 5 cm (2 in.)
20-30%	greater than 5 cm

The silt fraction is much larger, of course, if settling pond solids are included. All of these different fractions are subject to layering; i.e., as the pile is being formed and later, as erosion occurs, fines tend to be removed and larger particles may collect at the base. This phenomenon is especially evident in poorly engineered projects.

Culm piles occupy many acres of land in coal-bearing regions of the country. Until the 1950's, they were considered to be necessary features of the mining industry, and no attempts were made to reduce them or lessen their environmental impact. With the passage of the Air Pollution

Control Act of 1960, the Clean Air Act and its amendments, the Air Quality Act of 1967, Solid Waste Disposal Act of 1965, and several state legislations, interest in these disposal sites began to grow.

In 1965 and 1966 the U. S. Bureau of Mines and the Pennsylvania Department of Mines and Mineral Industries surveyed culm piles in Pennsylvania's anthracite region to determine the extent of that particular problem. The results indicated that 800 anthracite refuse piles, each containing at least 7,600 cubic meters (10,000 cu. yd.) of waste material, occupied a total surface area of 4,872 hectares (12,038 acres) and contained approximately 700 million cubic meters of solid waste (BU-086). Seventy three percent of the banks were located within two miles of a population center (>625,000 population). Twenty seven banks were reported to be burning. An additional 63 banks containing less than 7,600 cubic meters (10,000 cu. yd.) of waste were also noted but were not included in the survey because of their relatively small size.

During 1969, more than 395 million metric tons (435 million tons) of raw bituminous coal were processed in the United States, yielding 23% waste on the average (BU-086). This amounted to 91 million metric tons (100 million tons) of bituminous-generated wastes for just one year. Prior to 1969, 1,677 million metric tons (1,849 million tons) of bituminous washer plant reject had accumulated (BO-090).

5.2 Conventional Disposal Technology

The disposal method for coarse preparation plant waste traditionally involves transport to a disposal site. There the material is spread and compacted to achieve stability. Reclamation techniques are now commonly practiced.

5.2.1 Disposal Site

Disposal sites, until reclamation regulations were recently passed, were selected on the basis of size, and proximity to the preparation plant. Topographical features are more heavily considered now; valley-filling is advantageous in that two supporting sides are naturally sealed. Refuse deposits on flat terrain, on the other hand, require more manpower, equipment, and time since sides must be terraced, compacted, sealed, and vegetated. This type also offers more opportunity for spontaneous combustion since more surface is exposed to air. Active and abandoned strip mine pits can provide disposal sites for both coarse and fine preparation plant wastes.

5.2.2 Disposal Procedures

Most sites today receive some sort of preparation prior to deposition of refuse. Removal of existing vegetation aids in fire prevention. Water drains and diversions are often installed to prevent storm runoff from eroding the sides of the pile as well as to reduce acid mine drainage formation. Existing streams may be diverted from passage too close to the waste bank. Roads for trucks or other transport must also be constructed. In some cases, drainage basins for pile leachate and runoff are provided to collect water for neutralization treatment.

TABLE 5-2

REFUSE DISPOSAL (BU-086)

Company	Mine location	Mine name and type	Refuse produced, tons per day	Mode of transportation	Distance to disposal site (one way), miles	Refuse disposal cost/ton/mile
Bethlehem Mines Corp.	Barrackville, W. Va.	Idamay mine No. 44 (underground).	1,100	Truck..........	1.0	$0.28
Do..............	Ellsworth, Pa.	Mine 60[1] (underground).	2,800	Truck and aerial tram.	1.0 .5	.17 .10
Beth-Elkhorn Corp....	Jenkins, Ky...	Hendrix No. 22 (underground).	765	Truck..........	1.0	.13
Do..............	......do......	No. 27 mine (underground).	1,170	Conveyor belt and truck.	1.0	.13
Eastern Associated Coal Corp.	Rachel, W. Va.	Joanne mine (underground).	600	Truck..........	1.0	.16
Hanna Coal Co........	Cadiz, Ohio...	Georgetown Area (strip mine).	4,164	......do.......	1.0	.25
Pittsburg & Midway Coal Mining Co.	Hallowell, Kans.	Mine 19 (strip mine).	2,400	......do.......	2.0	.10
Do..............	Madisonville, Ky.	Colonial mine (strip mine).	1,100	......do.......	2.0	.10
U.S. Steel Corp......	Uniontown, Pa.	Ginger Hill (underground).	4,500	Underground rail mine cars and carryall.	4.0	[2].09

[1] Abandoned dumps; refuse from Mines 51 and 58 being disposed at Mine 60 dump by aerial tram.
[2] Direct cost only.

The disposal operation itself consists of several phases: transport of waste to the site; spreading and compaction; soil covering; and revegetation. The Bureau of Mines has recently reported the results of a technical and economic study of these phases of coal refuse disposal (BU-086). The following is a summary of their findings.

Transport is most commonly via truck although aerial trams, conveyor belts, and underground mine cars are in operation at some facilities. Costs for transport ranged from 6-19¢/metric ton/km (9-28¢/ton/mile). Table 5-2 gives further details of the studies from which these figures were obtained.

Spreading and compacting is usually accomplished with bulldozers and trucks. Compaction is necessary to hold the material in place. This procedure also serves to prevent spontaneous combustion to some extent by reducing the air supply to the combustible coal in deeper regions of the pile. It also is effective in preventing air and water pollution. A relatively new technique now in use is to sandwich the combustible waste between layers of noncombustible material such as clay, shale, coal sludge fines, fly ash, or industrial wastes (gypsum or cement plant by-products). Terracing is simultaneously done in some cases where simply sloping the edges does not provide sufficient stability to the pile. The economics of this disposal phase are relatively inexpensive compared to other phases. The Bureau of Mines reported handling costs ranging from 3.3-22¢/metric ton (3-20¢/ton). Details are given in Table 5-3.

Preparation for planting involves covering the refuse with adequate soil cover to support vegetation. The costs are quite high, ranging from $1,640 to 26,900 per

TABLE 5-3

REFUSE SPREADING AND COMPACTION (BU-086)

Company	Mine location	Mine name and type	Spreading and compaction equipment	Refuse handled, tons per day	Handling cost per ton
Bethlehem Mines Corp.	Barrackville, W. Va.	Idamay mine No. 44 (underground).	Trucks and bulldozer.	1,100	$0.03
Do.	Ellsworth, Pa.	Mine 60[1] (underground).	do.	2,800	.05
Beth-Elkhorn Corp.	Jenkins, Ky.	Hendrix No. 22 (underground).	do.	765	.16
Do.	do.	No. 27 mine (underground).	do.	1,170	.13
Eastern Associated Coal Corp.	Rachel, W. Va.	Joanne mine (underground).	do.	600	[2].11
Hanna Coal Co.	Cadiz, Ohio.	Georgetown Area (strip mine).	do.	4,164	.10
Pittsburg & Midway Coal Mining Co.	Hallowell, Kans.	Mine 19 (strip mine).	([3])	2,400	.20
Do.	Madisonville, Ky.	Colonial mine (strip mine).	Bulldozer.	1,100	.12
U.S. Steel Corp.	Uniontown, Pa.	Ginger Hill (underground).	Carryall.	4,500	([4])

[1] Abandoned dumps; refuse from Mines 51 and 58 being disposed at Mine 60 dump by aerial tram.
[2] Estimated.
[3] Refuse disposed of in pit areas. No spreading or compacting.
[4] Included in the cost of refuse disposal, table 2.

hectare ($665 to 10,900 per acre) as shown in Table 5-4; the latter figure was reported by a company who privately contracted this phase at a fee of $0.55/metric ton ($0.50/ton) of soil. These figures include soil, transportation, spreading, and compacting. The cost depends on availability of soil, hauling distance, size of equipment used, and depth of cover to be placed. In this particular survey, the metric tons of soil applied per hectare varied from 2,960 to 19,727 (3,263-21,750 tons). This last figure corresponds to the highest cost per hectare given above. A less costly technique being developed by the Bureau of Mines involves fly ash application instead of soil cover. This topic is described in detail in Section 5.4 where case studies are presented.

After the soil has been spread and compacted, usually in 20-30 cm layers, soil conditioners, fertilizer, mulch, and/or seed may be placed. Extensive studies are underway to determine the species of grasses, legumes, shrubs, and trees best suited to this growing environment. Preliminary results are reported in the literature (BU-086). Costs associated with planting vary widely depending, of course, on the quantity, variety, and availability of vegetation to be planted and on the use of soil additives, if any.

5.2.3 Environmental Aspects of Culm Piles

Several environmental issues exist with respect to the disposal of coal refuse in conventional culm piles. One of the most extensively studied problems is air pollution from burning refuse piles. Also, there is the coal industry's problem of acid mine drainage. In addition, physically

TABLE 5-4

SOIL COVERING AND PLANTING (BU-086)

Company	Mine location	Mine name and type	Soil cover, tons per acre	Soil cover, cost per acre[1]	Vegetation planted	Planting cost per acre[2]
Bethlehem Mines Corp.	Barrackville, W. Va.	Idamay mine No. 44 (underground).	3,300	$833	Grasses, black locust, white pine.	$165
Do...........	Ellsworth, Pa.	Mine 60[3] (underground).	21,750	[4]10,900	White pine, perennial rye, Kentucky fescue, Serecia lespedeza.	[5]442
Beth-Elkhorn Corp.	Jenkins, Ky...	Hendrix No. 22 (underground).	4,350	1,300	White pine, annual rye, Kentucky fescue, Serecia lespedeza.	50
Do...........	......do......	No. 27 mine (underground).	-	-	White pine, short leaf pine, loblolly pine.	[6]60
Eastern Associated Coal Corp.	Rachel, W. Va.	Joanne mine (underground).	13,235	1,323	Grasses, locust, white pine.	[7]148
Hanna Coal Co.....	Cadiz, Ohio...	Georgetown Area (strip mine).	4,538	1,598	Kentucky fescue, orchard grass, crown vetch.	48
Pittsburg & Midway Coal Mining Co.	Hallowell, Kans.	Mine 19 (strip mine).	8,700	700	Kentucky fescue, Serecia lespedeza, locust trees.	50
Do...........	Madisonville, Ky.	Colonial mine (strip mine).	6,525	700	Kentucky fescue, love grass, Serecia kobe, Serecia lespedeza.	50
U.S. Steel Corp...	Uniontown, Pa.	Ginger Hill (underground).	3,263	665	Crown vetch, black locust, pine trees, perennial rye grass, Kentucky fescue.	[8]455

[1] Includes soil, transportation, spreading, and compacting.

[2] Costs not footnoted are those for planting grasses and trees on soil cover not conditioned.

[3] Abandoned dumps; refuse from Mines 51 and 58 being disposed at Mine 60 dump by aerial tram.

[4] Privately contracted at 50 cents per ton.

[5] Includes cost of lime, paper mulch, fertilizer, grass seed applied by hydroseeding, and trees planted by hand. Weighted average cost for 1966, 1969, and 1970-71 projects.

[6] Soil cover not used. Trees and grasses planted directly on refuse not previously conditioned.

[7] Includes cost of lime, mulch, fertilizer, seed, and trees.

[8] Includes cost of soil conditioning, hydroseeding, and tree planting. Direct cost only.

degrading phenomena such as surface erosion and bank instability are not uncommon. Aesthetic objections also must be contended with in many situations; these are related to land use aspects.

In 1968 the Bureau of Mines identified 292 burning refuse banks in 13 of 26 coal-producing states by visual signs only (MC-096); a higher number would probably have been obtained if infrared photography had been used to detect below-the-surface fires. Coal refuse piles can be ignited by spontaneous combustion, freak accidents of nature, or by man. The causes of 66% of the 292 burning piles could be traced to spontaneous combustion.

The immediate effects of burning refuse piles entail air pollution by smoke, dust, toxic and noxious gases; thermal waves; and aesthetic effects. A number of deaths and accidents have been attributed to burning banks. In addition, the gases emitted have damaging effects on nearby vegetation, certain metal surfaces, and lead-based paint. Some forms of water pollution result from absorption of some of the gases and fine particulates generated. Smog can also form in vicinities of these piles during periods of precipitation.

Another important environmental aspect of culm piles is the acid mine drainage problem which can be described by the following set of reactions. Equation 5-1 describes the overall reaction, while Equations 5-2 through 5-4 show the stages through which the phenomenon proceeds.

$$2\ FeS_2 + 7\ O_2 + 2\ H_2O \rightarrow 2\ FeSO_4 + 2\ H_2SO_4 \qquad (5\text{-}1)$$

$$4\ FeS_2 + 15\ O_2 + 14\ H_2O \rightarrow 4\ Fe(OH)_3 + 8\ H_2SO_4 \qquad (5\text{-}2)$$

$$4\ FeSO_4 + 2\ H_2SO_4 + O_2 \rightarrow 2\ Fe_2(SO_4)_3 + 2\ H_2O \qquad (5\text{-}3)$$

$$Fe_2(SO_4)_3 + 6\ H_2O \rightarrow 2\ Fe(OH)_3 + 3\ H_2SO_4 \qquad (5\text{-}4)$$

Waste coal refuse containing pyrite will generate significant amounts of sulfuric acid and iron sulfate in the presence of air and water. To control this problem, several approaches are feasible:

- prevent acid mine drainage formation by cutting off supply of air and/or water
- remove iron from system by precipitation as insoluble salt
- neutralize acid mine drainage

5.3 Alternate Disposal Technologies

Several possibilities exist for alternate schemes for coal refuse disposal. These include:

- hydraulic backfilling of mine voids
- coal recovery from culm pile material
- utilization of refuse material in construction materials

The only one of the above practiced to any extent is coal recovery; even this approach does not completely solve the problem since there is still a substantial waste left over which must be disposed of.

A project was proposed by the Bureau of Mines in 1972 to demonstrate the feasibility of hydraulically injecting crushed coal waste into deep mine voids (LY-005). The main thrust of the program is mine subsidence control, not mine refuse disposal, although 230,000 cubic meters (300,000 cu. yd.) of refuse is involved. The site proposed was the flooded and dry mine voids in the Clark and New County coal beds beneath Scranton, Pennsylvania.

A survey taken in 1966 in the anthracite region of Pennsylvania revealed that contracted costs for backfilling of mine voids with culm bank material ranged from $1.60 to 4.70 per cubic meter ($1.25-3.60 per cubic yard) (MA-222). This included crushing, transport, and hydraulic backfilling.

During 1970, 31% of the annual anthracite coal production came from coal recovery from 97 culm and silt banks (US-079). This is now warranted since the small particles of coal, for which formerly there was no use and therefore were disposed of, are now highly useful as fuels and as lightweight aggregate (MA-222). Recovery of saleable coal seldom exceeds 20%, or 40% in the case of silt banks. Factors such as special contaminants in the refuse, location of the site, and its remoteness from potential markets must be considered. The processes used for coal recovery are generally the same as those employed for freshly-mined coal with modifications to handle larger quantities of dirt. One process, the Simdex Process, was designed especially for waste coal recovery. Details of this and other techniques are available in the literature (HA-186).

The Office of Coal Research and West Virginia University are currently studying several utilization schemes for culm pile materials. These include its use as aggregate in asphalt concrete material for road base construction and as an admixture in cement for mine stoppings (US-055). In this context, the strength and fire resistance of the waste is being determined. In general, utilization as a lightweight aggregate is hampered economically by the normally long distances between the culm piles and the potential market.

Use as landfill in housing and industrial developments and as backfill for strip mined areas are closely related. The fire prevention technique commonly practiced is mixing the waste and covering with a clay blanket; other methods can also be employed. The costs vary with each project, as determined by size, shape, and location of the bank; size and number of equipment required;

and distance to the landfill site. No real cost data are available, but it is estimated that costs should be lower than for backfilling mine voids (MA-222).

5.4 Case Studies - Culm Pile Reclamation

The Bureau of Mines has been actively engaged in the disposal and reclamation of mining wastes since passage of the Solid Waste Disposal Act of 1965. The potential agricultural uses of fly ash were recognized early, and in 1964 research into its use as a soil conditioner and nutrient in greenhouse studies was begun. During the next few years several field tests were initiated employing fly ash in reclamation of strip mine spoil areas. In 1970 and 1971 the program was expanded to include several coal refuse banks, or culm piles, in the vicinity of the Morgantown Energy Research Center (AD-016, CA-112, CA-135). Three such demonstration sites were visited during the course of this investigation, and the information obtained is summarized below.

Their first attempt at reclamation of a coal refuse pile was initiated in 1970 on a one-acre plot at the Bunker site. This pile, as most in the area, consisted of shale, rock, bone coal, and quantities of bituminous coal of various sizes. This refuse was hand-sorted waste from a deep-mining operation. A section of the pile had at one time been on fire; consequently, some quantities of "red dog" (oxidized pyritic materials) were also present.

The reclamation procedure began with a leveling operation. The plot was then treated with fly ash at a rate of 340 metric tons per hectare (150 tons/acre).

The source of the ash was that collected by electrostatic precipitators at the Fort Martin power plant, Allegheny Power System. A typical analysis of this ash is given in Table 5-5. The ratio of fly ash to refuse was adjusted empirically under laboratory conditions to obtain a near neutral condition. The ratio was then used to calculate the fly ash application rate based on a 15-cm plow layer depth of soil material. Depending on the extent of refuse acidity and ash alkalinity, these rates can vary between 170 and 900 kg/hectare. The rate used in this particular instance corresponded to a 4-5 cm application of fly ash.

The type of machinery used for leveling, spreading, and mixing fly ash with the refuse depends primarily on the terrain. Conventional farm equipment may be suitable in some cases, but more often heavier equipment is required. The equipment available to the Bureau of Mines included a bulldozer, front end loader, ripper, and rome plow. Large, powerful dump trucks are usually needed to haul the fly ash over the rough surfaces.

After the area was prepared, fertilizer and seed were applied by dry methods. These operations are normally carried out using a farm tractor and a rotary seeder. A granular 10-10-10 fertilizer was employed at the Bunker site at a rate of 1100 kg/hectare (1000 pounds per acre). Equivalent rates of a triple-16 or triple-12 type fertilizer have been used at other sites. A typical seed mixture applied in these projects is shown in Table 5-6; rate of application was ∿50 kg/hectare (∿45 pounds/acre). The birdsfoot trefoil is a legume which usually gives good results. The symbiotic nitrogen-fixation activity between legumes and root nodule bacteria is very beneficial, especially in areas where periodic

TABLE 5-5

TYPICAL ANALYSIS OF FORT MARTIN FLY ASH (AD-016)

Constituent	
Major elements, wt pct	
SiO_2	46.8
Al_2O_3	23.3
Fe_2O_3	17.5
CaO	5.7
MgO	1.1
Na_2O	.8
K_2O	2.0
TiO_2	.7
P_2O_5	.5
C	1.5
S	.4
Loss on ignition	5.1
Trace elements, ppm	
B	450
Cu	40
Mn	200
Mo	20
Zn	90
Bulk density, g/cc	1.15
pH	11.9
Fineness, pct through 200 mesh	91
Average size, micron	19

TABLE 5-6
SEED MIXTURE TYPICALLY USED IN BUREAU MINES RECLAMATION PROJECTS (AD-016)

Seed	Weight-Percent
Kentucky 31 Fescue (Festuca Arundinacea)	35
Red Top Grass (Agrostis Alba)	14
Orchard Grass (Dactylis Glomerta)	18
Birdsfoot Trefoil (Lotus Corniculatus)	5
	100

fertilizer application is impractical. Other varieties of grasses and other plants are being studied to determine their potential use in such projects. Those that have performed successfully include: weeping lovegrass, yello sweet clover, switchgrass, costal panic grass, and common goatsrue. Less successful results have been obtained with wild rye, deertongue, flat pea, and bluestem.

Procedures normally carried out during later growing seasons include a light fertilizer application in the spring equivalent to 225 kg/hectare (200 pounds/acre) of 10-10-10. Depending on availability of manpower, equipment, etc., some areas may be reseeded if the first seeding did not produce satisfactory results.

The results obtained at this site have been very encouraging. The dominant species, at least during the first year's growth, was red top; the growth rate of the other species picked up during the second growing season. While the first year's production cannot be expected to yield results comparable to surrounding farmed area, 1971 hay yields at this site were reported to be 2.2 metric tons/hectare (0.6 dry tons per acre). The average yield of hay grasses for the West Virginia area is 3.4 dry metric tons per hectare. Better results were predicted for the following year.

The beneficial effects of fly ash application on spoil and coal refuse are listed in Table 5-7. The neutralizing ability is the most important benefit since acidity is the limiting factor in plant survival in this type of material. Although detailed results have been reported for spoil areas, only limited data were available for culm pile treatment. These are presented in Table 5-8 for the Bunker site and two

TABLE 5-7
BENEFICIAL EFFECTS OF RECLAIMING SPOIL AND COAL REFUSE WITH FLY ASH (CA-112)

1. Acidic materials in spoil and refuse are neutralized.

2. Heavy clay and light sandy soils are changed to medium-texture soils.

3. Moisture-holding capacity increased.

4. Pore-space volume increased.

5. Grasses and legumes established as immediate cover that resists erosion and reduces stream pollution potential.

6. Forage yields from fly ash-reclaimed areas compare favorably with undistributed pastures and fields.

7. Consumption of tonnage amounts of fly ash.

8. Addition of some available major and trace plant nutrients.

9. Temperature of refuse surface is reduced, thus reducing moisture loss and preventing plant burning.

TABLE 5-8

EFFECT OF FLY ASH TREATMENT ON pH OF BITUMINOUS COAL MINE REFUSE (CA-112)

Site number and name	Coal seam mined	Area, acres	pH before treatment	Fly ash rate tons/acre	pH after treatment	Years since fly ash applied	Average current pH for area
A Bunker	Sewickley	1	2.7-3.0	150	7.2-7.6	3	7.1
B Shannopin	Pittsburgh	10	4.0-8.0	Variable[1]	4.0-8.0	2	7.4
C Cassville	Pittsburgh	7	3.0-3.8	150-200	4.4-7.6	2	6.0

[1] Fly ash was used to cover the refuse in order to prevent spontaneous combustion.

additional case studies described in this section. It is generally true that periodic reapplication of fly ash or other alkaline material is necessary to prevent the reclaimed area from converting back to its original acid conditions.

The second coal refuse area to be reclaimed by the Bureau of Mines was the Cassville site, a seven acre area located in rough, hilly terrain also consisting of hand-sorted waste from a deep-mining opeation. A great deal of effort had to be expended in clearing this particular area of trash before reclamation operations could proceed. Again, sections of the pile had been on fire at one time. Consequently a great quantity of "red dog" was scattered throughout the site. Another type of rock formation in abundance here was sulfur balls; these are pieces of pyritic material which are worn to this shape by the weathering process.

The initial work was done in 1971 on a 2-acre portion at the top of the hill. The procedures employed were similar to those used at the Bunker site. As indicated in Table 5-8, the fly ash application rate was 340-450 metric tons/hectare (150-200 tons/acre). The results were successful in that the field was well established with grass. As at the Bunker site, the dominant species at the end of the first growing season was red top, with other grasses becoming established afterwards. The available moisture content increased from 12.68% for untreated refuse to 18.46% for fly ash treated Cassville refuse (CA-112). The original pH range, 3.0-3.8, had increased to 4.4-7.6 when measured two years following the original ash application.

The third area included in this study was a 10-acre site on the west bank of the Monongahela River near Poland Mines, Pennsylvania. This site also had been on fire, but unlike the others described above, had received fly ash treatment for fire control. No further fly ash was applied as a reclamation effort; preliminary soil tests indicated that ripping should sufficiently mix the ash and refuse beneath to support grasses. However, after seeding and fertilizing, germination and growth were poor. Although the 1971 growing season was a dry season, the main reason for the poor results was attributed to the uneven fly ash distribution as indicated in Table 5-8. Consequently, the pH of the site was not favorable in most spots and the resulting vegetation was very sparse.

The following year, plans were made to treat the same area with an alkaline sludge resulting from an acid mine drainage neutralization process. Originally, the sludge application rate was to have been ∿340 metric tons/ hectare (∿150 tons per acre); however, only about 20-25 metric tons/ hectare (10 or 11 tons per acre) was actually applied because of difficulties encountered in obtaining the sludge. Results at the end of the 1972 growing season were somewhat disappointing, but since exceptional first year results are not expected in a project of this nature, the second year's growth would be more indicative of the extent of success. Again, an unexpected problem was encountered when the surface area was almost entirely dug up by the coal company. The only portion not harmed by the heavy equipment was a strip approximately six meters long and one or two meters wide which appeared to have a good growth of grasses established on it during March of this year (1974). Much of the vegetation established here was native grasses including barnyard grass, Johnson grass, and broomsage rather than the seeded species.

Costs for reclaiming coal refuse piles depend on many factors such as terrain, soil type and age, acreage, equipment used, legislative requirements, degree of reclamation desired, fly ash and other materials availabilities, and hauling distance. Since no soil cover is required and since most fly ashes could be obtained free of charge or at least at very low cost, costs would compare favorably with the usual reclamation procedures. In fact, the Bureau of Mines has assigned a market value to fly ash based on equivalent cost of materials found in the ash. These results are shown in Table 5-9. Estimated cost of reclamation by this method is $740 per hectare ($300 per acre) of previously leveled land; the cost of leveling is not included because it can vary extremely from one site to the next. Although this estimate has not been confirmed in practice, it appears that this fly ash technique can compare favorably with most coal refuse pile reclamation methods.

TABLE 5-9
EQUIVALENT COST OF MATERIALS FOUND IN FLY ASH (CA-112)

Material	Percent	Amount in 150-ton application	Market value
CaO	6.8	10.2 tons[2]	$ 41.60
K_2O	2.0	6,000 lb	
P_2O_5	.5-	1,500 lb[3]	232.20
Trace elements	800(ppm)	240 lb	
Fine sand and silt[1]	85.6	128 tons[4]	256.00
		Total	$529.80

[1] 100 - 14.4 percent (sum of lime, fertilizer, and ignition loss) = 85.6 percent fine sand.

[2] Lime at $4/ton.

[3] Fertilizer at $30/1,000 pounds.

[4] Fine sand and silt at $2/ton.

6.0 PHOSPHATE SLIMES

The annual U. S. production of marketable phosphate rock in 1970 was 35 million metric tons (BA-133, US-079). Florida has been the leading producer for many years, having 74% of the domestic production that year. Approximately 90% of that yield comes from the land-pebble region of central Florida (US-027). Other phosphate mining states include, in order of production capacity, Tennessee, North Carolina, Idaho, Montana, Utah, Wyoming, and California (BA-133). The total mine output for 1970 was 114 million metric tons (US-079). The difference between this figure and the total U. S. marketable production figure indicates that a vast amount of waste is generated during the beneficiation processes. These wastes take two forms, phosphate slimes and sand tailings. Close to one-third of the total tonnage of mined matrix is slime which, after ore processing, occupies approximately 50% more volume than the original matrix. When the mined-out area is used as the disposal site, about one-third more volume is needed than is available (BA-133, US-027).

As of 1968, accumulated phosphate wastes totalled 560 million metric tons covering 3,990 hectares in 16 states (BO-090). In Florida alone there are an estimated 434 million metric tons of slimes containing 56 million metric tons of P_2O_5, with an additional 3.6 million metric tons of P_2O_5 being added each year (BO-074). This amounts to ~38 million metric tons of slimes disposed of annually at 4-6% solids. Approximately one-third of the total tonnage of matrix mined is slimes.

6.1 Phosphate Mining and Beneficiation

Phosphate rock ore is mined by the open pit method in all four major production areas (Florida, North Carolina, Tennessee, and the western states). Some underground mining is also conducted in the Western fields. In Florida's land-pebble deposits, the overburden is stripped and the ore mined by electric dragline excavators equipped with buckets up to 38 cubic meters. The matrix is first placed in a sluice pit, then slurried at 40% solids and pumped through movable steel pipelines to washing plants, which may be several miles away (BA-133, US-027). In North Carolina a 55 cubic meter dragline is operating; as in Florida, the ore is transported hydraulically. This is not the case, however, in Tennessee and the Western fields where either truck or rail haul is used.

The ore beneficiation process usually involves size reduction, washing, desliming, and flotation, although some ores are marketable as mined, especially those deposits located in the western states (US-027). Most of the matrix from the other regions, however, must be treated prior to utilization. In the first step of beneficiation, the lumps of clay are broken up and phosphate nodules freed by hammer mills, grinding mills, or similar equipment. Clay particles adhering to the phosphate nodules are removed in log washers. Separations are then made on the basis of size. The coarsest fraction, +14 mesh to 1.9 cm (sometimes 16 mesh and 2.5 cm), is dried and marketed as high grade rock or can be blended with finer granulated material (-14, +200 mesh) obtained from other beneficiation steps. Figure 6-1 shows a process flow sheet for a typical Florida phosphate operation.

The second fraction (-14 or -16 mesh) consisting of fine clay, silica, and fine phosphates is subjected to desliming operations using cones or hydroseparators which

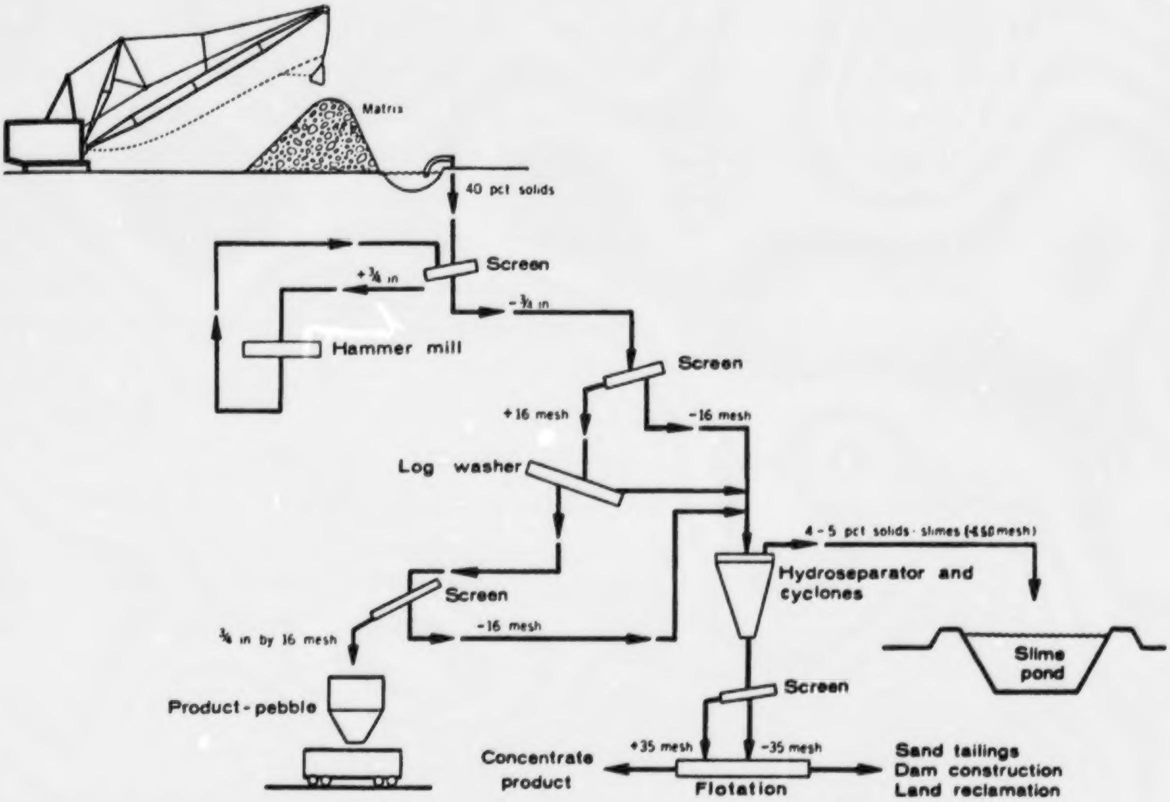
Matrix
40 pct solids
Screen
+3/4 in
-3/4 in
Hammer mill
Screen
+16 mesh
-16 mesh
Log washer
4-5 pct solids - slimes (-150 mesh)
Hydroseparator and cyclones
Screen
-16 mesh
3/4 in by 16 mesh
Slime pond
Product-pebble
Screen
+35 mesh
-35 mesh
Concentrate product
Flotation
Sand tailings
Dam construction
Land reclamation

FIGURE 6-1 - A TYPICAL PHOSPHATE ORE BENEFICIATION SCHEME (BO-074)

perform another size separation at 150-200 mesh. The finer fraction (i.e., the overflow) is waste slime, and is disposed of as a 4-6% solids slurry. The underflow is in some operations further subdivided at 35 mesh (AP-016, BA-133). If this separation is made, the 14 x 35 mesh material is beneficiated by gravitational separation equipment such as spirals, tables, belt separator, or coarse flotation devices. The 35 x 150 (or 200) mesh fraction or the entire underflow from the desliming is treated in flotation cells. Here, basically the fine phosphates are floated to the top and the sand tailings sink. The froth product is then put in a conditioning tank with sulfuric acid to remove the flotation agents, is washed, and is then mixed with an amine to float remaining silica away from the phosphate.

The phosphate losses from the washing and flotation processes can total up to 40% of the phosphorus in Florida land-pebble fields, and may be as high as 50% in some Tennessee areas (US-027). The phosphate concentrates from the beneficiation operations can then be further processed by one of three basic methods, depending on the ultimate utilization desired. These methods include acid treatment, thermal reduction, or thermal treatment without reduction. Further details of these processes are beyond the scope of this report.

6.2 Nature of Phosphate Rock Slime

Phosphate rock slimes are the fine wastes, usually minus 200 or 150 mesh, discarded from the washer as a 4-6% solids pulp. Tables 6-1 and 6-2 present typical mineralogic and chemical composition ranges. The phosphorus content of

TABLE 6-1

APPROXIMATE MINERALOGICAL WEIGHT COMPOSITION OF PHOSPHATE SLIMES SOLIDS*

Mineral	Percent
Carbonate fluorapatite	20 - 25
Quartz	30 - 35
Montmorillonite	20 - 25
Attapulgite	5 - 10
Wavellite	4 - 6
Feldspar	2 - 3
Heavy minerals	2 - 3
Dolomite	1 - 2
Miscellaneous	0 - 1

---

*From BA-133 and BO-074

TABLE 6-2

CHEMICAL COMPOSITION OF PHOSPHATE SLIMES SOLIDS*

Chemical	Typical Analyses, Percent	Range, Percent
P_2O_5	9.06	9 - 17
SiO_2	45.68	31 - 46
Fe_2O_3	3.98	3 - 7
Al_2O_3	8.51	6 - 18
CaO	14.00	14 - 23
MgO	1.13	1 - 2
CO_2	0.80	0 - 1
F	0.87	0 - 1
LOI (1,000°C)	10.60	9 - 16
BPL	19.88	19 - 37

---

*From BA-133 and BO-074

LOI - Loss on Ignition

BPL - Bone Phosphate of Lime

the solids is often as high as in the original matrix, 9-17% (BO-074, BA-133). However, because of its extreme colloidal and hydrophilic nature which greatly hinder dewatering, attempts to beneficiate this slime have not been very successful. Consequently, slimes are normally sent to settling areas where they settle quite rapidly to 10-15% solids. However, the rate is so slow beyond this point that even after two years, the solids content is usually only 25-35% (BA-133, US-027).

The Bureau of Mines is currently funding several programs to examine the basic characteristics of phosphate slimes. Their purpose is to prevent damage occurring from slime pond dam failures. The main areas under investigation include the following (KE-102):

- phosphate slimes characterization
- surface electronic studies
- relationship of thermodynamic properties to slimes stability
- dewatering studies
- empirical studies to improve settling rate.

6.3 Phosphate Slime Disposal Techniques

6.3.1 Conventional Method

The traditional method of slimes disposal is ponding in dammed, mined-out areas (BA-133, BO-074, US-027).

For every hectare-meter of matrix mined, 1.25 hectare-meters are required for slimes disposal. This means that in order for the mining area to provide sufficient storage space, dams must be built to increase the site's capacity. Some dams are constructed to retain slimes up to 12 meters deep. The ponds are built to rigid specifications normally out of quartz-sand tailings from the flotation effluent and overburden. Care must be taken to insure that no vegetable matter is present which could decay and lead to dam weakening. The top of the dam is sloped to the inside to reduce erosion of the outside wall. Inclusion of berms are recommended to prevent erosion on the outer toes of the dam. Spillways conduct the supernatant back to the fresh water reservoirs for recirculation or release to nearby streams during periods of heavy rainfall. Figure 6-2 shows minimum cross sections recommended for dam construction.

Water recycle is a very important aspect of slimes disposal and phosphate mining in general. A tremendous water requirement exists for the overall operation; approximately 18 x 10^8 liters are associated with phosphate slimes daily in the industry as a whole (BA-133). This water leaving the plant with the slimes accounts for about one-half of the total water requirements for both the mining and beneficiation processes. About 10% of the water used in disposal is retained by the solids even after many years of settling. This is a tremendous draw on the water resources, thus providing heavy incentive for maximum water reuse both for environmental and economic reasons. Water is recycled constantly, but the rate of drawdown varies with the rate of production of the processing plant, pond area, river pollution, rainfall, winds, amount of freeboard, and possible hurricanes.

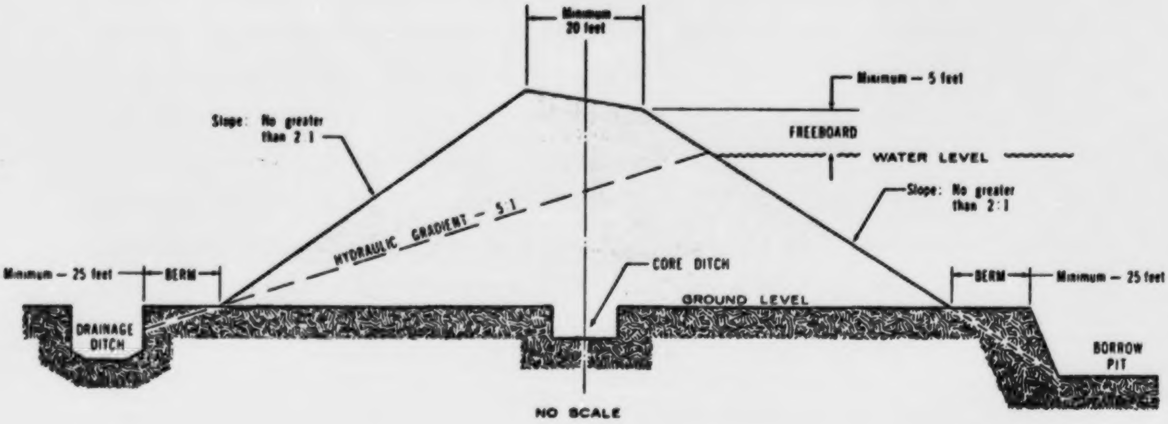
Minimum 20 feet
Minimum — 5 feet
Slope: No greater than 2:1
FREEBOARD
WATER LEVEL
Slope: No greater than 2:1
HYDRAULIC GRADIENT — 5:1
Minimum — 25 feet
BERM
CORE DITCH
BERM
Minimum — 25 feet
GROUND LEVEL
DRAINAGE DITCH
BORROW PIT
NO SCALE

FIGURE 6-2 - RECOMMENDED MINIMUM CROSS SECTION OF DAMS (BO-074)

The economics of slimes disposal by this method has been studied by the Bureau of Mines (BO-074). Cost figures reported were based on production capacity of a Florida phosphate mining company rather than on actual company figures. Therefore, the results can be applied to other phosphate businesses employing similar disposal procedures. Table 6-3 presents a summary of the results; more detailed information concerning the project is available in the literature (BO-074). The conclusions were that the net operating cost was $0.27 per metric ton of phosphate product, or approximately $0.55 per metric ton of dry slimes solids.

6.3.2 Alternate Disposal Methods

It has become evident in recent years that an improved method of slimes disposal is needed. The incentives for this are (1) the desire to avoid adverse effects from dam failures and (2) potentially lower handling costs if slimes storage volumes could be reduced and if water recycle could be improved.

In 1970, American Cyanamid announced that 52 acres (21 hectares) of slimes disposal area at Chicora Mine had been successfully reclaimed using a new technique. After several small-scale tests, a plant-scale project was carried out in which slimes thickener underflow (3.5% solids) was used to repulp dewatered sand tailings (CY-001, TI-021, BA-133, CU-020). This mixture was pumped into a trench 42 meters wide, 1,500 meters long, and 12 meters deep alternately from opposite sides. The trench was previously filled with water to a depth of 11 meters. The sand/clay mixture dissociated when it came in contact with the water in the trench.

TABLE 6-3.

CAPITAL AND OPERATING COSTS FOR SLIMES DISPOSAL[1]

Capital Costs

	Capital Investment
Slime pump stations (3 complete units)	$700,000
Pond spillways (10 required)	80,000
Excavator (for ditching)	60,000
Pumps (4 recirculating water)	160,000
Pipeline	200,000
Plant facilities	72,000
Plant utilities	76,000
Total cost (tax and insurance base)	$1,348,000
Interest during construction	33,700
Subtotal (depreciation)	1,381,700
Working Capital	280,200
Total capital investment	$1,661,900

Operating Costs

	Unit cost	Total	Cost per ton of product[2]
Direct cost:			
Raw materials and utilities:			
Fuel - 13.3 gal x $0.15 x 40 hr x 52 weeks	$4,100		
Power - 2,150 kwhr/hr x 8,760 hr/yr x $0.01 kwhr	188,300		
		$192,400	$0.045
Direct labor:			
16 man-hr/day - $3.00/man-hr x 365 day/yr	17,500		
Supervision - 15 percent of labor	2,600		
		20,100	.005
Maintenance:			
5 men - $7,000/yr	35,000		
Supervision - 20 percent of maintenance labor	7,000		
Material -	17,500		
		59,500	.014
Payroll overhead - 25 percent of payroll		15,500	.004
Operating supplies - 20 percent of maintenance		11,900	.003
Total direct cost		299,400	.071
Indirect Cost:			
40 percent of labor, maintenance, & supplies		36,600	.009
Fixed Cost:			
Taxes and insurance - 3 percent of total cost		40,400	.010
Depreciation - 5 percent of subtotal for depreciation and 10 percent for excavator		72,100	.017
Dam construction		938,000	.223
Total operating cost		1,386,500	.330
Credit for recirculated water		358,100	.085
Net operating cost		$1,028,400	.245

---

[1] From BA-133, BO-074.

[2] Cost per ton is based on 4,205,000 tons of product.

The sand settled rapidly, and the clay particles settled slowly over it. With new incoming sand, the gentle motion of sand encroaching on the clay liberated large volumes of water which were forced to the surface within a few hours. Masses of clay settled to a solids content of ∿35%. As more sand was added to this clay, the final settled product was 70-80% solids.

At the start of this test, the method disposed of 22% of the slimes being produced; this capacity increased to 45% by the end of the test. Both water circulation and settling requirements were reduced. A significant savings in slimes storage volume was also realized; by conventional method 69 hectare-meters for sand tailings plus 31 hectare-meters for clay (phosphate slimes, 20% solids) would have been required. With the new technique, however, only a total volume of 73 hectare-meters was taken up, or a savings of ∿27%. Handling costs were reduced by one-third. A final advantage of this new disposal process was that the resulting fill, 80% solids, possessed excellent load-bearing characteristics and was easily vegetated.

In a second plant-scale test involving reclamation of 24 hectares, slimes were made to flow through an existing settling area to an abandoned, flooded mine where they settled to 15-25% solids underwater in three months. Then a sand tailings/slimes underflow mixture was pumped in. Resultant clarified water was recirculated.

Incorporation of this method into the mining process would involve allowing the slimes to settle in the mine cuts. Overburden would be stacked as high as possible along the sides of the cut and would be used as cover material for the reclaimed slimes areas following solidification with sand. The problems foreseen in this becoming the accepted method of slimes disposal are the limited availability of sand tailings, which is a valuable material for other purposes as well, and a need to increase dewatering capability. The latter may possibly be improved by promoting a rolling and squeezing motion upon sand addition; this may be accomplished by having spaced retaining walls to keep the clays from migrating.

Studies of additional methods of phosphate slimes disposal have centered around improved and novel dewatering techniques. Investigations have been conducted by industry, TVA, and the Bureau of Mines. In general, the conclusions of almost all studies indicate that the dewatering techniques are not practically applicable to the industry's problem because (1) they require too much energy (chemical, mechanical, or thermal) thus making the process uneconomical, (2) the dewatered products have no potential utilization, and (3) the best results obtained still only achieve a 50% solids material. Descriptions of experimental investigations of various dewatering methods applied to slimes are reported in the literature (BA-133, BO-074, DE-073, DA-073, DA-074, ST-151).

6.4 Environmental Aspects of Phosphate Slimes Disposal

The environmental effects of phosphate slimes disposal by ponding were studied in several Florida river systems around 1950 (SP-034) and more recently in a North Carolina estuary (CA-125). Supernatant from the settling ponds, which is sometimes intentionally released to surrounding waters, contains high levels of phosphorus (13-40 μg of P/liter) (CA-125), thus creating the possibility of eutrophication of the water systems. Specht also monitored other parameters. Turbidity increased by ∿2.5%, but no harmful effects on fishlife were observed. A beneficial increase in the dissolved oxygen content was measured, while the biochemical oxygen demand remained unchanged. The alkalinity was not affected by the pond effluent. The only potentially toxic species was tall oil, a flotation reagent. However, none was found in the effluent waters. No increase in algae growth was noted. Carpenter, however, reported that slime pond supernatant did account for increased blue-green algae population in a North Carolina estuary over short periods of time (44 and 36 days). Effect on phytoplankton was studied, but no significant effects were observed. In general, no evidence of harmful effects from clarified slimes liquor have been found with the possible exception of increase in algae growth which could indirectly cause eutrophication.

Another potential hazard associated with phosphate slimes disposal by the conventional method is dam failure. Loss of the low solids slime over acres of adjacent land following dam failure has occurred several times in the Florida phosphate fields generating substantial legal action. Consequently, the dams are monitored constantly so that any structural weaknesses may be detected early.

Most phosphate mining companies also monitor streams below their plants on a daily basis. The parameters measured include water flow, suspended solids, phosphate, and fluorine. No reports of groundwater monitoring were found in the literature although this would be another area of potential environmental concern.

6.5 Case Study - Reclamation of Slimes Disposal Area

In 1972 the Florida phosphate industry produced more than 29 million metric tons of phosphate, which represented almost three-fourths of the nation's and one-third of the world's phosphate output. More than 75% of this was mined in a single county, Polk County, generally recognized as the phosphate capital of the world. Reclamation of the mined-out areas is being accomplished at an accelerated rate. In the last ten years, the phosphate industry has reclaimed more than 10,000 hectares of land. An additional 1,300 hectares were in the process of being reclaimed by Florida mining companies as of June, 1973. In Polk County alone, over 81,000 hectares of land are owned by the mining industry. Eventually all of this may be mined although present technology does not make this feasible. At any rate, these numbers point out the large effect reclamation of land will have on the future of that county.

One housing development in this county situated on a mined-out area, Christina, was visited by Radian personnel. The area was mined over forty-five years ago, and has just recently been developed by IMC Development Corporation. The development is located in a forest, much of which established itself naturally on the spoil areas after mining operations had ceased. The old mining pits are now lakes abundantly populated with fish. The slimes disposal ponds presented the only constraint on freely planned development since they did not possess the support necessary for housing. However, they were successfully converted to forested parks and greenbelts.

Near this residential development is the Jekyl-Hyde Golf Course, originally another project of IMC Development Corporation for the use of its employees. The area was mined-out in the late 1930's, with 16 of its 75 hectares used as slimes disposal area.

IMC began reclamation in March, 1961 and most of the tailing used for cover material had been pumped to the site by 1964 when IMC terminated development. Revegetation in this case presented few problems. The tailing material was contoured and seeded with bermuda type grasses and native shrub and trees. Fertilization requirements were minimal owing to the high phosphate content in the tailing material. An added note here might be that even unreclaimed slime ponds are not of zero value. They generally become heavily vegetated, marshy areas forming habitat for game birds and animals as well as a large population of snakes, rodents and predators. The combination of high fertility, low toxicity, and subtropical climate encourage verdant growth in all cases.

The reclaimed area was first used as a small par-3 course covering 10 hectares (24 acres). It was later converted to a conventional course, although incomplete, consisting of 3 holes. In 1969, the land was sold to a private individual who continued the development of the land to its present 18-hole configuration, along with a swimming pool and planned tennis courts. The recreational complex is at the present time an open (semi-private) club.

7.0 TACONITE TAILINGS DISPOSAL

The major fraction of iron ore mined in the United States is mined in the Lake Superior district encompassing the states of Minnesota, Michigan, and Wisconsin. The raw ore is found in several forms. The original formation consisted of iron oxides, carbonates and silicates in conjunction with layers of chert. In localized regions enrichment of the minerals occurred through oxidation and groundwater leaching. However, a major fraction of the ore remains unaltered. The iron containing fraction, when it contains greater than 20% iron as magnetite, is referred to as taconite. Large reserves of taconite exist in the Mesabi range, north of Duluth and in the Marquette range in upper Michigan. Since the mid 1950's when Reserve Mining pioneered the recovery of usable iron from taconite, the industry has grown to where over half the usable domestic ore is produced from taconite or jaspilite (LA-099).

A typical taconite mining and beneficiation plant will include the following elements:

1. a surface mine
2. a crushing and grinding operation
3. a magnetic separation of iron ore from tailings

7.1 Nature of Taconite Tailings

Composition of tailings is variable depending on ore seam being mined and on the mechanical details of the beneficiation process. Detailed analyses have been made of the tailings produced by the Reserve Mining Company's plant at Silver Bay, Minnesota. A representative analysis is given in Table 7-1 (RE-093). The composition strongly resembles a typical silicious sedimentary material.

Tailings are frequently classified as coarse and fine. Fine tailings generally will pass a 325 mesh screen. Table 7-2 contains a typical screen analysis for total tailings, again taken from Reserve Mining data (RE-093). Calculations performed by Weston (WE-096) indicate that the fraction 325 mesh or smaller contributes over 90% of the total surface area available for leaching. This represents approximately 40 wt. % of the total tailings. Table 7-3 gives the analysis of the particle size-area relationship (WE-096).

The tailings apparently provide good structural stability. For example bricks made from tailings demonstrate compressive strengths of 5,500-7,250 psi (3,800-5,000 newtons/cm^2) with water absorptivities of about 7% in 24 hours (WE-096). Representative values for clay brick are 3,000 psi (2,100 new tons/cm^2) and 8.2% respectively.

The fact that the Weston report (WE-096) proposes construction of ski slopes with tailings again attests to the inherent structural stability of tailings.

The mining industry as practiced today requires large processing facilities with correspondingly large quantities of tailings. Over 100 million tons of crude taconite ore are mined annually (LA-099). If one assumes an

TABLE 7-1

TYPICAL ANALYSES OF NATURAL SEDIMENTS AND RESERVE'S TAILINGS (RE-093)

	Tailings %
Iron	14.93
Silicon	33.03
Aluminum	0.35
Calcium	1.67
Magnesium	2.55
Manganese	0.37
Titanium	0.030
Phosphorus	0.026
Sodium	0.20
Potassium	0.08
Sulfur	0.03
Lead	0.005
Zinc	0.004
Nickel	0.002
Copper	0.004
Molybdenum	<0.001
Vanadium	<0.001
Cobalt	0.002
Chromium	0.004
Cadmium	0.0003
Carbon	0.11
Hydrogen	0.10
Oxygen	46.40
Total	99.90

TABLE 7-2

TYPICAL TOTAL TAILS SCREEN ANALYSIS (RE-093)

Mesh	Micron	Weight % Finer
3	6730	96.7
4	4760	90.4
6	3360	81.6
8	2380	72.8
10	1680	66.3
14	1190	61.6
20	841	57.5
28	595	55.5
35	420	53.6
48	297	51.9
65	210	49.6
100	149	45.9
150	105	41.7
200	74	38.0
270	53	34.7
325	45	32.5
	30	24.7
	20	18.4
	10	9.3
	5	5.3

TABLE 7-3

TAILINGS SURFACE AREA DISHCARGED PER DAY DISTRIBUTION

BY PARTICLE-SIZE RANGE (WE-096)

Through/On	Average Particle Size[1] microns	Total Weight tons/day [2]	Average Percent (by Wt.)	Dry Volume cu.ft./day [3]	Unit Surface Area sq.ft./cu.ft. [4]	Total Surface Area sq.ft./day [5]	Percent of Surface Area in Size Range	Cumulative Surface Area Distribution
MICRON SIZES								
5/		4,350	6.5	66,000	1.84×10^5	1.21×10^{10}	35.84	35.84
10/5	7	3,420	5.1	52,000	1.38×10^5	7.15×10^9	21.18	57.02
20/10	15	7,400	11.1	113,000	6.25×10^4	7.05×10^9	20.88	77.90
44*/20	32	10,600	15.9	144,000	3.0×10^4	4.30×10^9	12.73	90.63
MESH SIZES								
270/325	48	3,140	4.7	47,500	2.08×10^4	9.85×10^8	2.92	93.55
200/270	64	3,350	5.0	51,000	1.58×10^4	8.05×10^8	2.39	95.94
150/200	90	2,750	4.1	41,800	1.06×10^4	4.42×10^8	1.31	97.25
100/150	125	3,000	4.5	45,500	7.7×10^3	3.50×10^8	1.04	98.29
65/100	177	2,130	3.2	32,500	5.45×10^3	1.77×10^8	.52	98.81
48/65	250	1,670	2.5	25,500	3.80×10^3	9.7×10^7	.29	99.10
35/48	355	1,670	2.5	25,500	2.82×10^3	7.2×10^7	.21	99.31
28/35	500	2,000	3.0	30,300	1.80×10^3	5.44×10^7	.16	99.47
20/28	610	2,270	3.4	34,500	1.04×10^3	3.59×10^7	.11	99.58
14/20	1,000	2,950	4.4	44,700	8.9×10^2	3.98×10^7	.12	99.70
10/14	1,408	3,550	5.3	50,800	6.8×10^2	3.47×10^7	.10	99.80
8/10	1,900	4,400	6.6	67,000	5.0×10^2	3.47×10^7	.10	99.90
6/8	2,850	4,100	6.1	62,300	3.2×10^2	1.99×10^7	.06	99.96
4/6	4,000	2,750	4.1	41,800	2.5×10^2	1.04×10^7	.03	99.99
3/4	5,000	1,230	1.8	18,600	1.9×10^2	3.54×10^6	.01	100.00
Total		66,730				337.6×10^8		

Average Tailings Density	132 lbs/cu.ft.
Average Tailings Volume	15.2 cu.ft./ton

*325 mesh

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[1] Sizes assumed to be median values between the "through" screen and "on" screen sizes.
[2] 1 ton = 0.9078 metric ton
[3] 1 cubic foot = 0.028 cubic meter
[4] 1 sq. ft./cu. ft. = 0.033 m^2/m^3
[5] 1 square foot = 0.0929 square meter

average iron content of 25% in the ore, with beneficiation to 60%, the total amount of tailings becomes about 55 million metric tons per year. Examples of tailings rates from individual plants are (WE-096):

Reserve Mining	~59,000 metric tons per day
Erie Mining	~50,000 metric tons per day
Eveleth Taconite Co.	~63,000 metric tons per day

7.2 Disposal Techniques

Two general methods are in use for the disposal of taconite tailings. The first and most prevalent is ponding with eventual reclamation of the tailings ponds. The second, used solely by Reserve Mining, is direct disposal into Lake Superior.

7.2.1 On-Land Disposal

The taconite plants using on-land disposal generally use ponds with dams or dikes constructed from tailings. In the case of the Erie plant, coarse tailings are sluiced directly to either a 1,300 acre (500 hectare) or a 700 acre (300 hectare) settling pond. The tailings fines are passed through thickeners and then discharged to the ponds. Water is recycled. The Eveleth plant also operates on a closed loop basis. In this case the coarse tailings containing 17-20% water are separated and hauled by truck to the pond site for dike construction. The fines go to a hydroseparator and then to a thickener before discharging to the tailings pond. In this case the use of coarse tailings for dike construction reduces dusting problems. Pond waters are recirculated to the plant.

The Erie plant has been the subject of rather extensive experimentation in reclaiming tailings ponds. The company has instituted a "Multiple Resource Management Plan" designed to utilize the following resources: minerals, water, wildlife, and recreational uses (LA-099, p. 137). The tailings basins are capable of handling 19 million metric tons of tailings per year. As mentioned above the coarse tailings are used for dam and dike construction. During studies conducted to determine the optimum methods for dike stabilization the conclusion was reached that while the tailings are not toxic to plant life, their fertility is very low. Through a planned program of fertilization, seeding and mulching, it has been possible to revegetate tailings basins within a single growing season following spring planting. Although the revegetation research is still incomplete, it has been noted that native trees are beginning to reestablish. The main vegetation is still alfalfa, however. The fine nature of the tailings have required the planting of low plants with strong root systems to stabilize the soil. During 1967 and 1971 approximately 40 hectares of basin were reclaimed. These initial results, although modest, are promising but much research remains before reclamation of infertile tailings basins becomes routine. Additional details are presented in the case study for this waste material.

7.2.2 Lake Disposal

The disposal of tailings directly to Lake Superior has become the subject of much controversy and a Federal suit is currently in progress against Reserve Mining. Reserve Mining now discharges over 60,000 tons per day of tailings into the lake depending on a "density current" to carry the material into a deep trough. The actual environmental effects of this disposal method are the subject of the litigation and until the court action is complete, they should probably be discussed only in general terms because of conflicting data. At any rate problems sited range from damaging spawning grounds for rainbow trout to eutrophication to the discharge of "asbestos-like" fibers which enter drinking waters.

This disposal method clearly would not be approved for new plant construction and may be altered by court order before the Reserve plant completes its estimated 10 additional years of useful life.

7.3 Case Study - Erie Mining's Tailings Reclamation Program

The beneficiation of taconite ore produces a tailing material which is generally disposed of by ponding. Erie Mining Company was chosen as the subject of this case study on the basis of their extensive research and publications in the revegetation of tailing basins. An on-site visit was made to the Erie Mining Company plant and mine on March 13, 1974. The facility is located approximately 65 miles north of Duluth, Minnesota near the town of Hoyt Lakes. The plant location is shown in Figure 7-1 along with the rail and harbor facilities for shipment. The capacity of the plant is some 9.35 million metric tons per year of concentrate pellets containing approximately 65% iron.

The ore being mined contains approximately 31% total Fe and 22.5% magnetic iron. The overall mining-beneficiation process is given schematically in Figure 7-2. Mining is conducted by the drill and blast method with electric shovels used to load the raw ore. The ore is then crushed in gyratory crushers to approximately 17 centimeters (6 3/4 in.). The coarse ore then passes through a cone crusher set to 2.9 cm (1 1/8 in.) and shorthead cone crushers set to less than 0.5 cm. (3/16 in.). This product, termed fine ore, then passes into the concentrator plant. Rod mills followed by ball mills are used to obtain a minus 325 mesh product. Three stages of magnetic separation are used; a rough separation after the rod mills, a cleaner separation following the ball mills and a finisher section after the cyclone separator. Tailing is removed from each stage and flows to a hydroseparator where coarse tailing is separated for use in dam building. Tailing is pumped at 40% solids to the tailing basin and allowed to settle.

A map of the plant area is shown in Figure 7-3. At present there are two tailing basins covering approximately 890 hectares (2,200 acres). Additional area of about 320 hectares (800 acres) will be added by the year 2,000 and is expected to be sufficient for the plant life.

The plant operates on a total water recycle basis. Water is reclaimed from the tailing at the concentrations

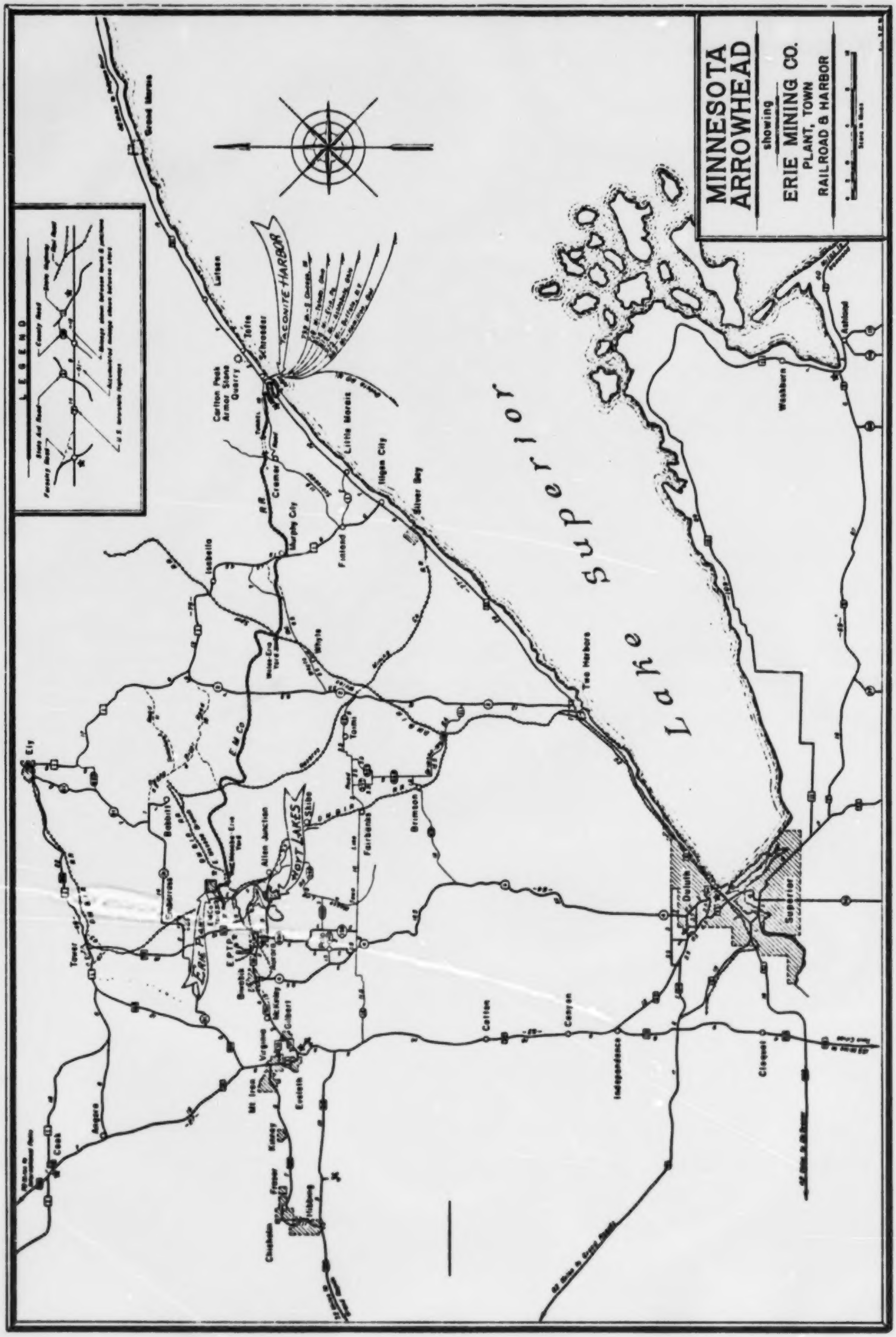
MINNESOTA ARROWHEAD
showing
ERIE MINING CO.
PLANT, TOWN
RAILROAD & HARBOR
LEGEND
TACONITE HARBOR
ERIE PLANT
HOYT LAKES
Lake Superior
Grand Marais
Lutsen
Tofte
Schroeder
Carlton Peak Armor Stone Quarry
Little Marais
Illgen City
Silver Bay
Cramer
Murphy City
Finland
Isabella
Two Harbors
Duluth
Superior
Ely
Babbitt
Allen Junction
Brimson
Fairbanks
Tower
Aurora
Biwabik
McKinley
Gilbert
Virginia
Mt Iron
Eveleth
Kinney
Cook
Angora
Hibbing
Chisholm
Cotton
Canyon
Independence
Cloquet
Washburn
Ashland

FIGURE 7-1

ERIE MINING COMPANY COMMERCIAL TACONITE PLANT

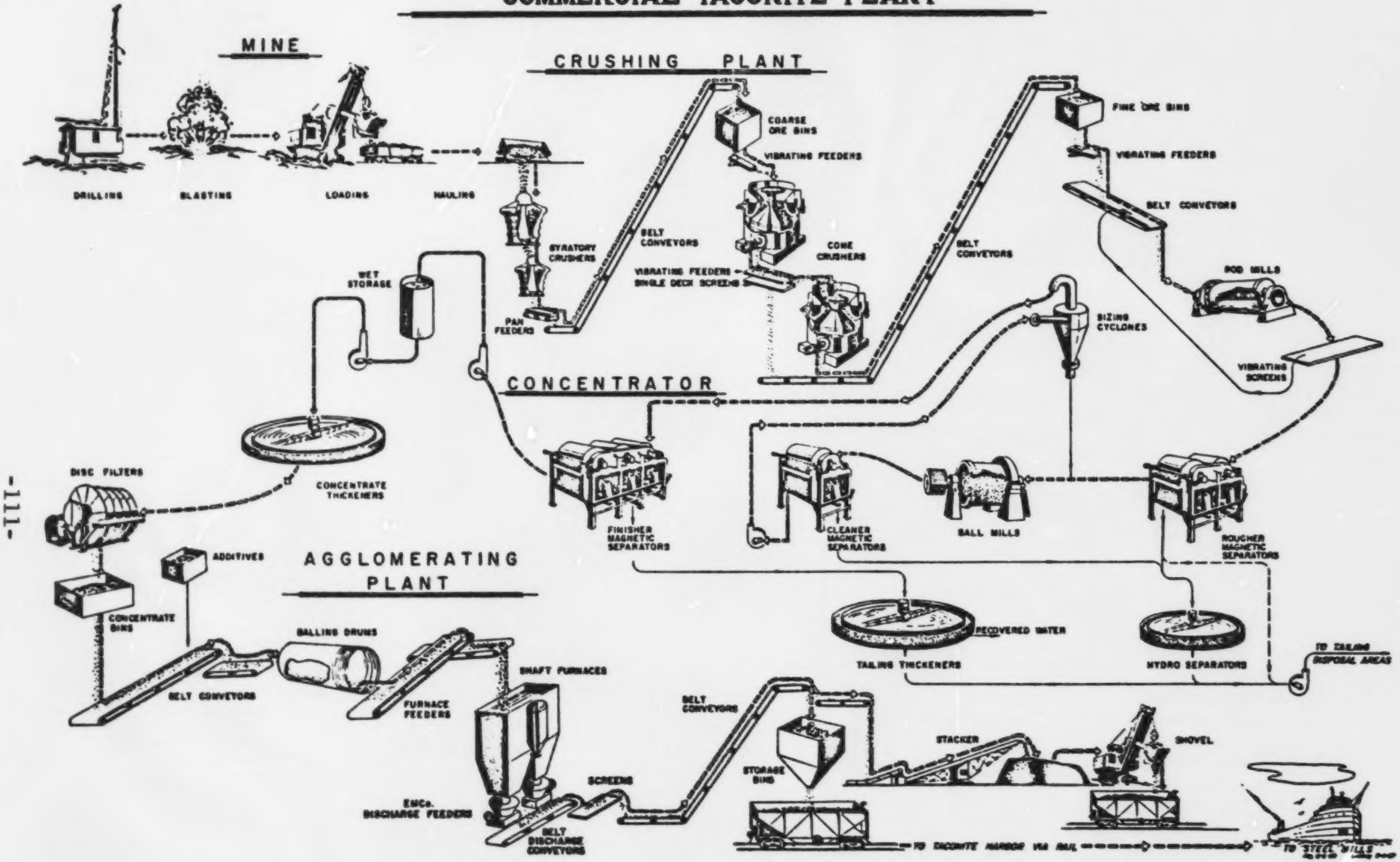
MINE
DRILLING
BLASTING
LOADING
HAULING
CRUSHING PLANT
GYRATORY CRUSHERS
PAN FEEDERS
BELT CONVEYORS
COARSE ORE BINS
VIBRATING FEEDERS
CONE CRUSHERS
VIBRATING FEEDERS
SINGLE DECK SCREENS
BELT CONVEYORS
FINE ORE BINS
VIBRATING FEEDERS
BELT CONVEYORS
ROD MILLS
VIBRATING SCREENS
SIZING CYCLONES
CONCENTRATOR
WET STORAGE
CONCENTRATE THICKENERS
FINISHER MAGNETIC SEPARATORS
CLEANER MAGNETIC SEPARATORS
BALL MILLS
ROUGHER MAGNETIC SEPARATORS
TAILING THICKENERS
RECOVERED WATER
HYDRO SEPARATORS
TO TAILING DISPOSAL AREAS
DISC FILTERS
ADDITIVES
CONCENTRATE BINS
AGGLOMERATING PLANT
BELT CONVEYORS
BALLING DRUMS
FURNACE FEEDERS
SHAFT FURNACES
EMCo. DISCHARGE FEEDERS
BELT DISCHARGE CONVEYORS
SCREENS
BELT CONVEYORS
STORAGE BINS
STACKER
SHOVEL
TO TACONITE HARBOR VIA RAIL
TO STEEL MILLS

FIGURE 7-2

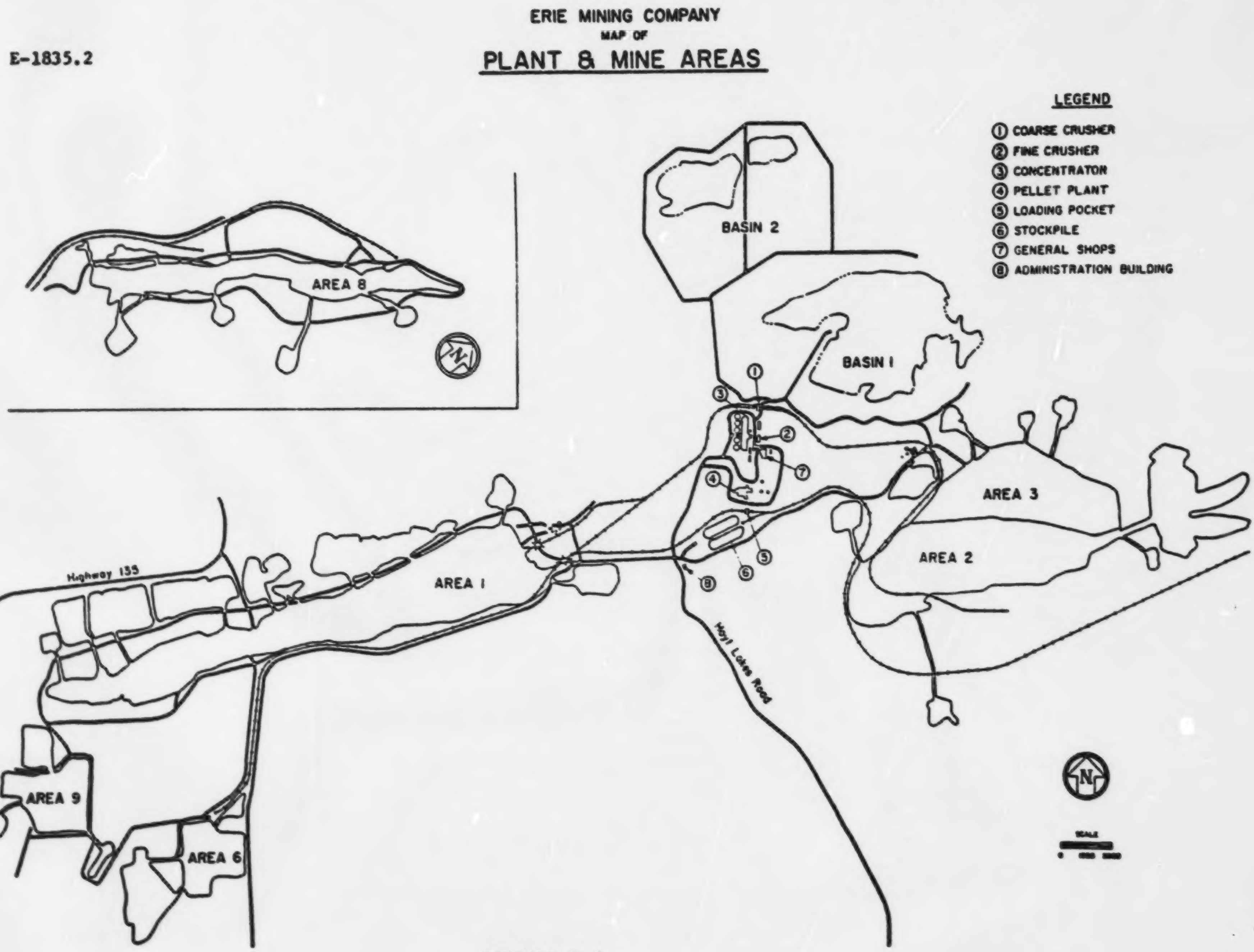
ERIE MINING COMPANY
MAP OF
PLANT & MINE AREAS
LEGEND
① COARSE CRUSHER
② FINE CRUSHER
③ CONCENTRATOR
④ PELLET PLANT
⑤ LOADING POCKET
⑥ STOCKPILE
⑦ GENERAL SHOPS
⑧ ADMINISTRATION BUILDING
AREA 8
N
BASIN 2
BASIN I
AREA 3
AREA 2
AREA I
Highway 135
Hoyt Lakes Road
AREA 9
AREA 6
N
SCALE
①
②
③
④
⑤
⑥
⑦
⑧

FIGURE 7-3

and from the tailing basins. The plant water usage rate is 9,500 liters per second (150,000 gpm). Approximately 5% of this is make-up water from an Erie reservoir; 75% is reclaimed from the thickeners and 20% from the tailing basins.

As mentioned previously, the tailing basin side walls are constructed primarily from coarse tailing. The normal slope is 1.5:1-2:1 but stable slopes of ~3:1 are used in limited areas.

Basin construction is straightforward. Tailings are sluiced at about 40% solids to the dam site and are contoured with rubber tired graders. The normal lift is 6 meters with a 48 centimeter rill and 6 meter bench left between lifts to control erosion. Pumping is through a multistage system using rubber lined 41 cm pumps. Thirty-six centimeter pipe is used from the concentrator to the first booster station; 30 cm. pipe from that point on.

Distribution of tailing to the basin is achieved through a manifold containing a number of flexible pipes. During winter operation, only the main pipe is used; this operating procedure requires frequent moving of the outlet pipe but reduces freezing problems. Structural stability is such that machinery can be operated on the material immediately after deposition. In isolated cases slimes have collected after a rainfall to form unstable pockets. On covering with fresh material the instability is eliminated.

Tailing size distribution for the Erie operation is approximately the following:

-325M	48.8%
-200 to +325M	7.0%
-65 to +200M	17.6%
-10 to +65M	18.8%
+10M	7.8%

The material consists of about 75% silica with the balance mainly iron oxide. Erie studies have shown no plant toxicity and virtually no plant nutrient value in the tailing.

The major portion of the tailing pond interior is kept under water. At present about 71 hectares (175 acres) of the pond interior is vegetated primarily for dust control. The primary revegetation work is concerned with stabilization of the back slopes.

Actually, two types of revegetation regimes are conducted, one for the backslopes and one for the interior. The primary difference is the necessity for permanence of the vegetation. A second factor is avoiding encouragement of algae growth in the water, since the water is recycled for plant use.

The interior work was approximately 280 kg/hectare (250 lb/acre) of a 20-20-0 fertilizer, enough to support 2-3 years of annual growth. By the end of this period fresh tailing covers the vegetation and the procedure must be repeated. The primary vegetation for interior work is annual rye. In addition millet and barley are planted to provide forage for the geese and ducks which use the ponds.

The current rate of revegetation is 40-60 hectares (100-150 acres) per year, primarily in the interior. Each lift of the dam is reclaimed as it becomes available; this amounts to about 10-12 hectares (25-30 acres) per year.

The more difficult problem is reclamation of the backslopes. Extensive research has been performed to develop procedures. Seeding may be done in the spring or summer but more successful results have been obtained by dormant seeding in the fall, i.e., the first week was in October. The most demanding requirement is fertilizer. As mentioned above, the tailing has no fertility value. For vegetating side walls, a long lasting application of 1,100 kg/hectare (1,000 lb/acre) of an 11/4810 fertilizer is applied. The material requires at least 100 kg N/hectare (90 lb of N per acre). Phosphorus presents a unique problem and they attempt to apply at least 390 kg/hectare (350 lb/acre).

The problem with phosphorus relates to its mobility in the tailing. Nitrogen moves through the substrate allowing root growth to penetrate to a reasonable depth for soil holding properties. Phosphorus, on the other hand, tends to remain where it is placed and must be worked into the soil mechanically. Therefore the fertilizer is applied to the backslopes and then worked in to a depth of 13-15 centimeters with a "clodbuster". Then seed is applied at the rate of 50 kg/hectare (45 lb/acre) with a hydroseeder. Four and a half metric tons per hectare hay or straw mulch is then applied and an asphalt task used. South slopes require that the seed be covered to protect them from lethal temperatures; a chain drag is used for this purpose.

Washouts soon after planting sometimes require a re-seeding, but the major problem in revegetation is fertilizer availability. They have had to cut back to 500 kg/hectare (450 lb/acre) in some cases because of allocations.

The vegetation used for permanent stabilization includes at least 50% clover or legume; the most successful single species is birds foot trefoil. Alfalfa has given excellent results in providing nitrogen fixation.

The water in the basin is relatively high quality. Because it is returned to the process, no formal monitoring program is required. Even seepage is retained within plant boundaries. Table 7-4 shows a comparison between basin wastes, seepage and typical waters from the Embarrass River adjacent to the plant.

Cooperation of the Erie Plant personnel during this study was outstanding. They are understandably and justifiably proud of their work with the tailing basin. Although taconite tailing is perhaps a unique material to reclaim, the principals followed should be applicable to many other similar problem areas.

TABLE 7-4

WATER QUALITY

	Basin	Seepage	Embarass River
pH	8.1	8.1	6.9
TS, mg/ℓ	250	189	152
TSS, mg/ℓ	13	2	2
TDS, mg/ℓ	237	187	150
Turbidity, mg/ℓ	12	1	---

8.0 GYPSUM FROM PHOSPHORIC ACID MANUFACTURE

Phosphoric acid is an essential intermediate in the manufacture of phosphate fertilizers. Wet process phosphoric acid production involves the chemical attack of phosphate rock by a strong mineral acid, usually sulfuric acid. The naturally occurring composition of phosphate rock can be represented by the formula $3Ca_3(PO_4)_2 \cdot CaX_2$ where X may be a halogen, hydroxyl, etc. The most prevalent form is fluorapatite, $3Ca_3(PO_4)_2 \cdot CaF_2$. When this calcium salt reacts with sulfuric acid, the overall reaction products are phosphoric acid and calcium sulfate, a compound relatively insoluble in phosphoric acid.

$$Ca_3(PO_4)_2 + 3H_2SO_4 \rightarrow 3CaSO_4 \downarrow + 2H_3PO_4 \qquad (8\text{-}1)$$

The reaction between sulfuric acid and fluorapatite is as follows:

$$3Ca_3(PO_4)_2 \cdot CaF_{2\,(s)} + 10H_2SO_{4\,(aq)} + 10\ x\ H_2O_{(\ell)}$$

$$\rightarrow 6H_3PO_{4\,(aq)} + 2HF_{(aq)} + 10\ CaSO_4\ x\ H_2O_{(s)} \qquad (8\text{-}2)$$

The value of x may be 0, 1/2, or 2 corresponding to anhydrite, hemihydrate, or dihydrate (gypsum), respectively. The form of the precipitate is determined by process conditions such as:

- extent of P_2O_5 recovery from rock,
- filtration rate of $CaSO_4/H_3PO_4$ slurry,

- temperature, and
- strength of product acid.

Accordingly, three major process variations are available based on the form of the by-product. The processes are referred to as the anhydrite, hemihydrate, and dihydrate processes. Other variations are also in operation, sometimes involving two-stage combinations of the above.

The process most prevalent in the United States is the dihydrate process. A typical flowsheet for this method is given in Figure 8-1. To assure gypsum formation, the temperature in the digestor is maintained at 75°C. Since the reaction is exothermic, the amount of heat generated is a function of the H_2SO_4 concentration which is controlled between 77 and 98% (usually 93%). The efficiency of P_2O_5 extraction from the rock is typically >96%, and the acid product strength is 30-32%. More detailed descriptions of this and other processes are reported in the literature (BA-133, CR-052, MA-257, RO-113).

In most operations here, the gypsum by-product is treated as a waste and traditionally disposed of in diked ponding areas. In other countries, especially where naturally occurring deposits of gypsum are scarce, the more common practice is to market this product for its sulfur value or for raw material in gypsum wallboard, cement, or plaster of Paris manufacture.

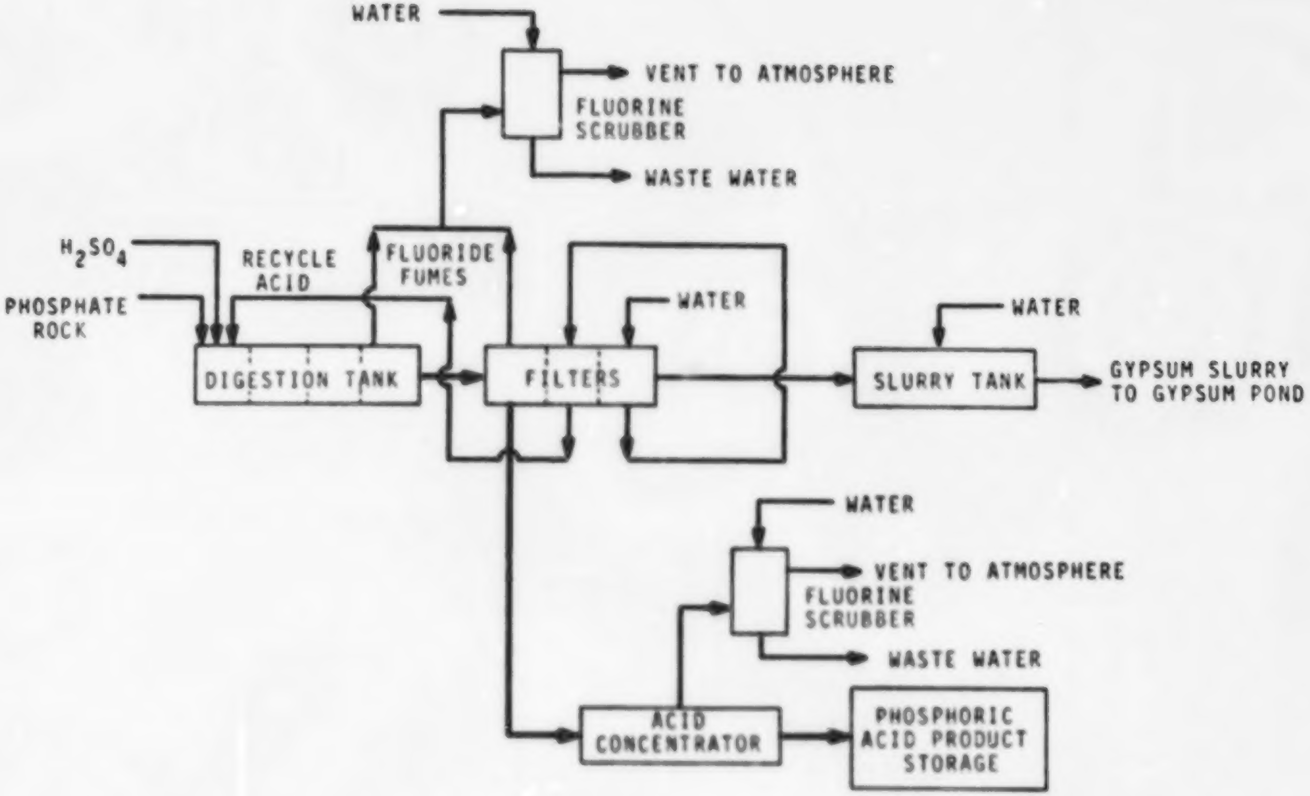
WATER
VENT TO ATMOSPHERE
FLUORINE SCRUBBER
WASTE WATER
H_2SO_4
PHOSPHATE ROCK
RECYCLE ACID
FLUORIDE FUMES
DIGESTION TANK
FILTERS
WATER
WATER
SLURRY TANK
GYPSUM SLURRY TO GYPSUM POND
WATER
VENT TO ATMOSPHERE
FLUORINE SCRUBBER
WASTE WATER
ACID CONCENTRATOR
PHOSPHORIC ACID PRODUCT STORAGE

FIGURE 8-1 - WET PROCESS PHOSPHORIC ACID FLOWSHEET FOR DIHYDRATE PROCESS (BA-133)

8.1 Nature of By-Product Gypsum

8.1.1 Chemical and Physical Properties

The composition of by-product gypsum from phosphoric acid production (phosphogypsum) is dependent on the phosphate rock composition and on the process conditions. Table 8-1 compares natural and by-product gypsum. The natural gypsum is much purer; components of fluorapatite, calcium phosphate and calcium fluoride, account for the majority of the impurities present in phosphogypsum. The influence of rock source on chemical composition is illustrated in Table 8-2, while Table 8-3 shows the effect of process variations. Note that in general, the total phosphate content of the gypsum from the dihydrate process is higher than that from the combination process in which hemihydrate crystallized during the first stage is converted to the dihydrate in the second stage. The phosphate content of the gypsum is important for several reasons. First, it is an indication of the extraction efficiency of the process. Secondly, some of the phosphate crystallizes within the gypsum lattices and adversely affects the marketing properties of the by-product. This aspect is dealt with in further detail in Section 8.3 below. The composition can be altered, if necessary, by washing operations involving reslurrying and classifying. Typical results are shown in Table 8-4.

The particle sizes of phosphogypsum is typically very fine, predominantly minus 100 mesh BSS (British Standard Sieve) (MU-060). A typical size distribution is presented in Table 8-5. Gypsum precipitates as needle-like, rhombic-shaped crystals, twins, and clusters (RO-113)., The factors

TABLE 8-1

COMPARATIVE CHEMICAL ANALYSES OF NATURAL AND BY-PRODUCT GYPSUM (GO-072)

	Natural gypsum, %	By-product gypsum, %
$CaSO_4 \cdot \frac{1}{2}H_2O$	6.73	Nil
$CaSO_4 \cdot 2H_2O$	92.36	92.84
$Ca_3(PO_4)_2$	Nil	2.25
CaF_2	Nil	2.66
SiO_2	0.39	0.95
Fe_2O_3	0.15	0.01
Al_2O_3	Nil	0.79
Other impurities	0.37	0.50
Total impurities	0.91	7.16

TABLE 8-2

COMPOSITION OF TYPICAL BY-PRODUCT CALCIUM SULFATES FROM DIFFERENT ROCK SOURCES (ST-155)

By-product calcium sulfate	Rock source	Chemical analysis, wt. % (anhydrous basis)						
		S	CaO	SiO_2	Al_2O_3	Fe_2O_3	P_2O_5	F
A	Florida	16.9	40.2	11.8	0.4[a]	—	0.9	—
B	Tennessee	20.6	39.4	7.5	0.6	0.4	1.9	0.4
C	Morocco	22.4	40.9	—	—	—	1.5	1.3
D	Morocco	17.1	30.2	1.2	1.7	0.7	—	—
E	Kola Peninsula	18.0	30.9	0.7	0.5	0.3	—	—

[a] Total Al_2O_3 and Fe_2O_3.

TABLE 8-3

COMPOSITION OF BY-PRODUCT GYPSUM FROM WET-PROCESS PHOSPHORIC ACID MANUFACTURE[a] (MU-060)

Process and sample no.	Combined water, %	SiO_2 and insoluble matter, %	R_2O_3, %	MgO, %	CaO, %	SO_3, %	Total phosphate, %	Water-soluble phosphate, %	Total fluorine, %	Water-soluble fluorine, %
Dihydrate										
1	20.07	1.35	—	—	32.09	45.13	1.08	0.14	0.41	0.18
2	20.36	1.22	0.44	0.32	31.28	43.51	0.86	0.36	0.91	0.32
3[b]	19.68	2.95	0.27	—	31.34	43.75	0.53	0.09	—	—
4[b]	19.41	2.02	2.65	—	31.10	43.04	0.77	0.08	1.19	—
5[b]	20.49	1.80	0.96	0.07	31.73	44.93	0.55	0.07	0.75	0.10
Hemihydrate-dihydrate										
6	—	—	—	—	—	—	0.47	0.12	1.25	0.28
7	20.52	1.94	0.46	—	31.30	44.12	0.60	0.33	0.80	0.38
8[b]	20.23	0.98	0.25	0.44	32.15	44.70	0.39	0.08	0.20	0.06
9[b]	19.36	6.43	0.28	0.08	29.92	42.73	0.16	0.04	0.18	0.05
10[b]	—	—	—	—	—	—	0.36	0.02	0.15	0.04
11[b]	—	—	—	—	—	—	0.34	0.01	0.17	0.01
12[b]	20.01	3.16	0.36	Tr.	31.30	43.98	0.38	0.06	0.15	0.04

[a] Courtesy of Yoshino Gypsum Company; samples taken during various periods of plant operation.

[b] Gypsum repulped and washed again after filtration.

TABLE 8-4

COMPOSITION OF BY-PRODUCT GYPSUM AS AFFECTED BY WASHING (GO-072)

	By-product gypsum as received from phosphoric acid plant, %	By-product gypsum after reslurrying and classifying, %
Loss on ignition at 230°C	19.12	20.25
SO_3	45.33	45.22
CaO	33.08	32.66
Total P_2O_5	1.06	0.76
SiO_2 and insolubles	1.10	0.98
Fe_2O_3	0.009	0.005
Al_2O_3	0.03	0.01
MgO	0.04	0.02
NaCl	0.92	Nil
	Probable composition	
$Ca_3(PO_4)_2$	2.32	1.66
$CaSO_4 \cdot \frac{1}{2}H_2O$	6.85	0.47
$CaSO_4 \cdot 2H_2O$	89.33	96.65

TABLE 8-5

PARTICLE SIZE OF BY-PRODUCT GYPSUM FROM PHOSPHORIC ACID PLANT (GO-072)

Size	% smaller than given size
BSS	
100	88.2
150	59.1
200	46.2
Microns	
33	18.6
23.1	7.7
18.6	4.1
12.3	3.0
7.1	2.1
4.0	1.5

related to particle size and other crystal characteristics include:

- sulfate concentration,
- phosphoric acid concentration,
- impurities in the rock, and
- slurry concentration.

These effects have been studied by several investigators (RO-113).

8.1.2 Production Quantities of Waste Gypsum

For every metric ton of phosphate rock processed, 1.5 metric tons of by-product gypsum are produced (BA-133, SC-150). Similarly, for every metric ton of P_2O_5 product, 4.5 metric tons of gypsum result. These relationships indicate that, for large plants, waste disposal can create a large-scale problem.

In 1969 wet process acid production in the United States was estimated to be 5,300,000 metric tons (5,800,000 short tons) P_2O_5 (BA-133). This is equivalent to a gypsum disposal problem amounting to 24-26 million metric tons (26,000,000 short tons).

8.2 Conventional Disposal Practices

In many countries including the United States, phosphogypsum cannot compete with natural gypsum as a raw material. Therefore, common practices have developed whereby it is simply dumped in diked disposal areas or, in some cases, into the ocean. This section describes common disposal techniques and associated environmental aspects.

8.2.1 Description of Methods

In a typical phosphoric acid plant, the precipitated gypsum is separated from product acid by a complex filtration system. The filter cake is then washed and discharged from the filter containing 18-35% free moisture (BO-095). In one type of disposal system, water sprays sluice the material into a receiving vessel or hopper, from which it either flows by gravity or is pumped to a gypsum pond. The pond area should be 0.2 hectares per daily metric ton P_2O_5 produced (0.5 acres per daily ton P_2O_5 production). The rate of gypsum accumulation is approximately ∿0.1 hectare-meters per year (∿one acre-foot per year) per daily ton P_2O_5. As the solids settle, the supernatant is recycled although in some cases it is discharged to the environment following adjustment of pH, phosphate, and fluorine (see Section 8.2.2).

The design of ponds has been developed through many years of experience. The Florida Phosphate Council has adopted certain criteria for dike design, as illustrated in Figure 8-2. The ponds are usually divided into sections, which may be filled, drained, and emptied alternately. The gypsum slurry will flow outward from the point of discharge

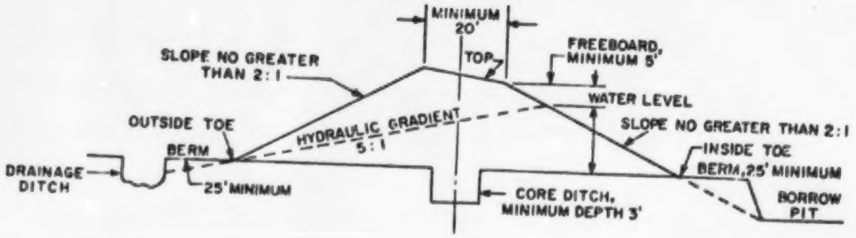
MINIMUM
20'
TOP
FREEBOARD, MINIMUM 5'
SLOPE NO GREATER THAN 2:1
WATER LEVEL
OUTSIDE TOE
HYDRAULIC GRADIENT 5:1
SLOPE NO GREATER THAN 2:1
BERM
INSIDE TOE
BERM, 25' MINIMUM
DRAINAGE DITCH
25' MINIMUM
CORE DITCH, MINIMUM DEPTH 3'
BORROW PIT

FIGURE 8-2 - RECOMMENDED MINIMUM CROSS SECTION OF DAM (BO-095)

at an angle of repose of only 1°. One unusual feature of gypsum ponds is that the settled solids may be used to build up the height of the dikes. Some dikes have been built up as high as 30 meters (100 feet). The disadvantages of this practice include the necessity of mechanical rehandling and increased slurry pumping costs. A typical range of pond construction costs as a function of plant capacity are shown in Figure 8-3.

In a few facilities in the United States the filter cake is removed as a dry cake, and is transferred to the disposal site via conveyor belt or other solids handling equipment. This is not a common practice, however, since it is much more expensive than a slurry handling system (BO-095).

While ponding is the most common method of disposal in the United States, European plants typically dispose of their waste by ocean- (or sea-) dumping (BE-188). There are several reasons for this: there is less land area available for any type of land disposal; since no phosphate mining is done in Europe, mined-out phosphate areas are not available as disposal sites; the acid plants are located near sea coasts, estuaries, rivers; thus the need to recycle water via ponding wastes is not a strict requirement.

The normal discharge method when ocean-dumping is used is slurrying with water (sea water if possible) at 5 or 10% solids (BE-188, BO-095). Pumping is usually employed, although it is much less expensive if gravity flow can be utilized; the cost for pumping was reported to be $0.30/dry

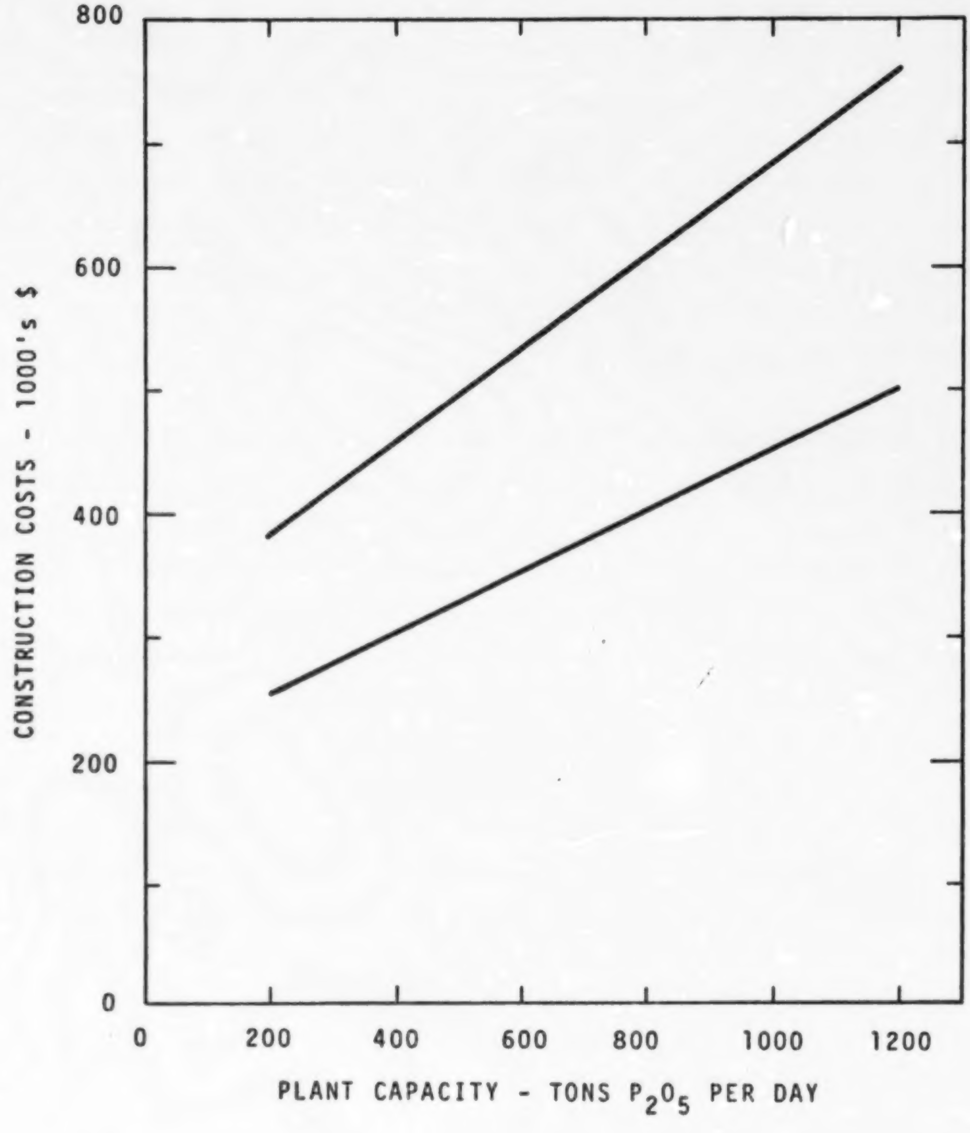

FIGURE 8-3 - TYPICAL GYPSUM POND CONSTRUCTION COSTS (BA-133)

metric ton compared to only $0.10/dry metric ton for gravity systems (BE-188). Good dispersion in the ocean must be assured; this may be achieved by jetting seawater into the pipelines near point of discharge. In some cases companies are required to install intermediate dissolution devices; gypsum is more soluble in seawater than in fresh water. It is important in this type of operation to avoid hemihydrate formation because it is difficult to filter and it may cause scaling in the pipes.

Barges are used for sludge-dumping when distance to discharge point is too great for pipelining to be feasible. The slurry is pumped into open barges where it settles; the resulting supernatant is allowed to overflow the sides. When full, the barges are hauled out to the outfall of the estuary and the gypsum is released through bottom hatches.

The most expensive disposal method in use involves truck transport of dry sludge to abandoned pits, quarries, and mines. European cost estimates are reported to be as high as $1.50/dry metric ton (BE-188). This method is only employed to any extent in Germany, especially in the Ruhr area.

European land disposal practices involve transport of the gypsum by conveyor belt, pipe, or ditches to a disposal site, usually on company-owned land. In regions where strict environmental regulations are not yet in effect, the slurry is simply dumped at the site and excess water allowed to soak into the ground. The cost for this type of disposal is approximately $0.25/dry metric ton, not including the cost of the land (BE-188). In some instances, this technique has been utilized in the reclamation of land after flooding by the seas. The gypsum acts as an ion exchanger, replacing sodium ions adsorbed by the soil with calcium ions.

8.2.2 Environmental Aspects of Phosphogypsum Disposal

The aspect of gypsum disposal of most interest to the phosphoric acid industry is water recycle. The gross water requirements for the wet process acid industry ranges between 83,000 and 170,000 liters per metric ton P_2O_5 (20,000-40,000 gal. per ton P_2O_5) (BA-133). While ∿80% water recovery is generally achieved, some is released to the environment, especially during periods of heavy rainfall. For example, a 540 metric ton P_2O_5 per day acid plant may discharge up to 300 liters/sec. (5,000 gpm) during a heavy rainfall period, while the average over a year is between 2,000 and 4,000 liters/metric ton P_2O_5 (500-1,000 gal./ton P_2O_5). The composition of the supernatant changes in the pond until equilibrium is reached, at which time the results shown in Table 8-6 are typical. Prior to discharge, adjustment of pH, fluoride, and phosphate is necessary. The exceptions are plants situated where evaporation rates are very high, regulations are less than stringent, or the subsurface drainage rate is high.

The partial pressure of soluble fluorides can be significant. Although losses by evaporation on a windy day have been reported to be as high as 90 kg/day (200 lb/day), the corresponding ambient air concentration was only 1 ppb. Although fluorine present in phosphate rock is essentially an air pollution problem in wet process acid production, it becomes a water-related problem since plant gas streams are

TABLE 8-6

TYPICAL EQUILIBRIUM COMPOSITION OF GYPSUM POND WATER (BA-133)

Contaminant	Concentration, mg/ℓ
P_2O_5	6000-12,000
Fluoride	3000-5000
Sulfate	2000-4000
Calcium	350-1200
Ammonia	0-100
Nitrate	0-100
pH	1.0-1.5

scrubbed with dilute fluosilicic acid followed by pond water for fluorine control. Typical fluoride distribution in wet process phosphoric acid production is presented in Table 8-7. Recovery from some of the effluent streams is practical for fluoride marketing value; for example, 80% recovery from the acid concentrator gas effluent can be achieved. However, only 50% removal from the reactor and filter gas streams are possible. Recovery for resale here would not be warranted. All scrubbed fluoride not recovered for marketing ultimately winds up in the gypsum pond where its soluble concentration builds up until equilibrium is reached.

Pond discharge treatment usually consists of lime neutralization and settling. In most cases, double-liming is practiced, while triple-liming is required in a few instances. A flow sheet for a typical double-liming process is shown in Figure 8-4. In the first mixing tank, slaked lime or slaked lime slurry is mixed with pond water for 10-15 minutes (one hour in some cases). Limestone is not as reactive, but is used in some processes. The resultant slurry is transferred to an agitated settling tank or clarifier for several hours. During this first stage, the pH is raised to 3.6-3.8, and fluoride precipitates as CaF_2; typical fluoride concentration at this point is 40-60 mg/ℓ. The soluble phosphate content is only slightly reduced.

The supernatant from the first clarifier passes to a second mixing tank where more slaked lime is introduced. Again, 10-15 minutes in the mixing tank followed by several hours for clarification is generally required. In this stage, remaining fluoride precipitates, probably as fluorapatite. Most of the phosphate is precipitated in the second stage. Final supernate compositions are as follows:

TABLE 8-7

FLUORIDE DISTRIBUTION IN WET PROCESS PHOSPHORIC ACID PRODUCTION (BA-133)

	% of Total Fluoride in Rock			
Fluoride Disposition	Typical Range	Typical Values		ERCO
Evolved from Reactor and Filters	4-7	5	5.5	5
Evolved from Concentrator	35-45	40	41.9	60-65
Remaining in Gypsum	25-30	30	27.8	20-25
Remaining in Acid Product	20-30	25	24.8	10
Reference	a	b	a	c

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[a] A. V. Slack, Editor, Phosphoric Acid, Parts 1 and 2, Marcel Dekker, Inc., New York, New York (1968).

[b] E. J. Fox, J. M. Stinson, and G. Tarbutton, "Superphosphate, Its History, Chemistry and Manufacture," United States Government Printing Office, Washington, D. C. (1964).

[c] J. H. Forster, "16th Ontario Industrial Waste Conference of the Ontario Water Resources Commission," Niagra Falls, Ontario, June (1969).

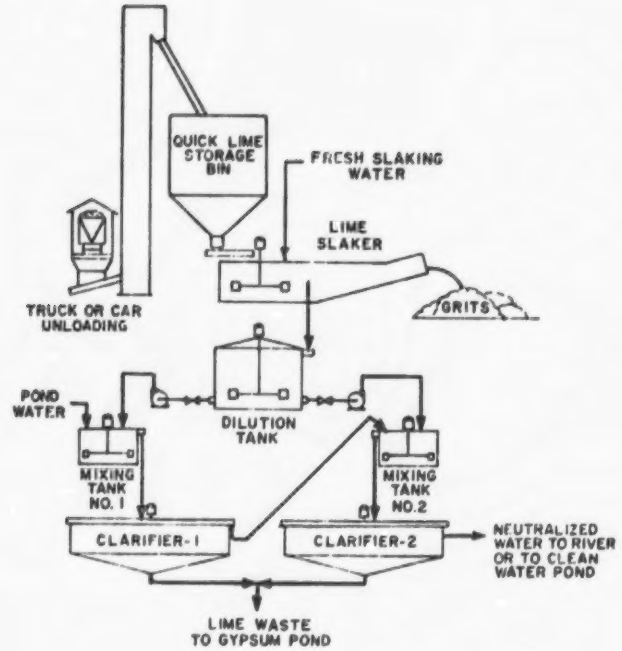
QUICK LIME STORAGE BIN
FRESH SLAKING WATER
LIME SLAKER
GRITS
TRUCK OR CAR UNLOADING
DILUTION TANK
POND WATER
MIXING TANK NO. 1
MIXING TANK NO. 2
CLARIFIER-1
CLARIFIER-2
NEUTRALIZED WATER TO RIVER OR TO CLEAN WATER POND
LIME WASTE TO GYPSUM POND

FIGURE 8-4 - POND WATER NEUTRALIZING SYSTEM (BO-095)

pH: 6-7

fluoride: 5-20 mg/ℓ

phosphate: 10-30 mg/ℓ

The results of a recent survey showed that operating costs averaged ~\$2.10/metric ton P_2O_5 (\$1.90/ton), while the range was \$1.00-3.30/metric ton P_2O_5 (\$0.90-3.00/ton P_2O_5) (BA-133).

Although groundwater contamination from gypsum pond leachate and runoff is a potential hazard, no data are available. However, no harmful effects have been detected to date by state or federal agencies.

8.3 Alternate Disposal Methods

Alternate disposal methods for phosphogypsum discussed in this section entail various utilization schemes, some of which are quite highly developed in countries other than the United States. Because of the abundant supply of natural gypsum deposits here, there has not been as strong an incentive to develop utilization technology as has been felt in Japan, Europe, and other areas. The Florida Phosphate Council has been studying potential uses, but to date no practical results have been obtained. The following paragraphs present a summary of progress made in foreign countries. The majority of the applications have been made in production of gypsum wallboard, gypsum plaster, plaster of Paris, cement, stucco, building blocks, ammonium sulfate fertilizer, and recovery of sulfuric acid or sulfur.

Production of ammonium sulfate is based on the Merseburg Process, treating by-product gypsum or anhydrite with ammonia and carbon dioxide to form ammonium sulfate and calcium carbonate (GO-072). Figure 8-5 is a simplified flow sheet for this process. Although it was developed for natural gypsum as a raw material, it has been modified to work well with phosphogypsum. The residual fluoride and P_2O_5 do not affect the product (GY-007), although certain process operations can be troublesome. Organic impurities may decompose, releasing CO_2 which may cause foaming. Phosphates can result in difficult separation of $CaCO_3$ from the product. Table 8-8 summarizes the industrial application of the Meresburg Process.

Phosphogypsum's utilization in products such as cement and gypsum wallboard is hampered by the following parameters:

- total P_2O_5
- unattacked P_2O_5
- syn-crystallized P_2O_5 (dicalcium phosphate substituted in crystal lattice)
- water-soluble P_2O_5

The third parameter listed is the most important one since it retards setting time and product strength and because there are no simple means of neutralizing its effects (MA-257). The presence of soluble fluorine compounds lowers the final strength, and also shortens the setting time. Another

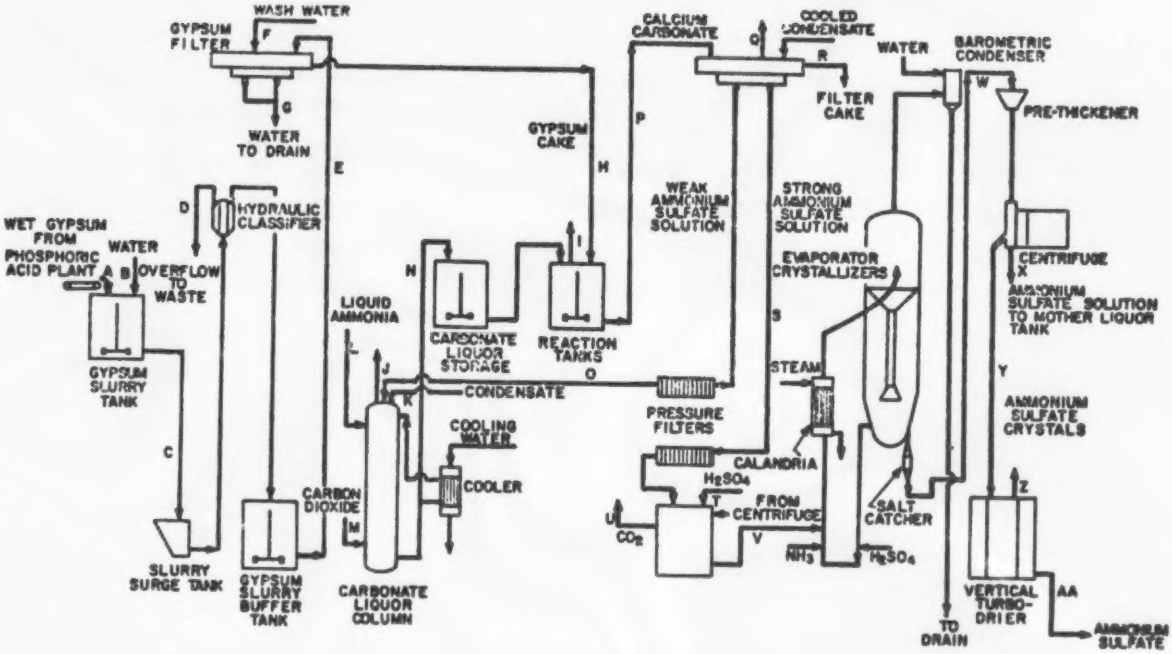
WASH WATER
GYPSUM FILTER
F
G
WATER TO DRAIN
E
GYPSUM CAKE
H
CALCIUM CARBONATE
Q
COOLED CONDENSATE
R
FILTER CAKE
WATER
BAROMETRIC CONDENSER
W
PRE-THICKENER
P
D
HYDRAULIC CLASSIFIER
WET GYPSUM FROM PHOSPHORIC ACID PLANT
A
WATER
B
OVERFLOW TO WASTE
GYPSUM SLURRY TANK
N
I
CARBONATE LIQUOR STORAGE
REACTION TANKS
WEAK AMMONIUM SULFATE SOLUTION
STRONG AMMONIUM SULFATE SOLUTION
EVAPORATOR CRYSTALLIZERS
CENTRIFUGE
X
AMMONIUM SULFATE SOLUTION TO MOTHER LIQUOR TANK
LIQUID AMMONIA
L
J
K
CONDENSATE
O
S
STEAM
Y
PRESSURE FILTERS
AMMONIUM SULFATE CRYSTALS
COOLING WATER
COOLER
C
CALANDRIA
H_2SO_4
T
FROM CENTRIFUGE
U
CO_2
V
NH_3
H_2SO_4
SALT CATCHER
Z
CARBON DIOXIDE
M
SLURRY SURGE TANK
GYPSUM SLURRY BUFFER TANK
CARBONATE LIQUOR COLUMN
VERTICAL TURBO-DRIER
AA
TO DRAIN
AMMONIUM SULFATE

FIGURE 8-5 - SIMPLIFIED FLOW DIAGRAM FOR PRODUCTION OF AMMONIUM SULFATE FROM PHOSPHOGYPSUM (GO-072)

TABLE 8-8

PLANTS MANUFACTURING AMMONIUM SULFATE FROM CALCIUM SULFATE (GY-007, GO-072)

Operating company	Date of installation	Raw materials	Annual capacity, tons *	Evaporation	Engineered by
1. BASF (IG Farben Industrie A/G) Oppau, Germany	1913-1914	Gypsum and anhydrite	Up to 500,000 by 1928; later reduced to 110,000	—	—
2. BASF (IG Farben Industrie A/G) Leuna, Germany	1918	Gypsum	Up to 600,000 by 1943; damaged by bombs in 1944; believed rebuilt	—	—
3. Wasag-Chemie Stickstoffwerke Krefeld, Germany	1958	Phosphogypsum	45,000	Krystal, triple effect	OSAG, Linz
4. ICI, Billingham. U.K. (closed, 1971)	1923	Anhydrite	600,000	Own design	ICI
5. ONIA Toulouse, France	—	Anhydrite	130,000 in 1951	Believed Lurgi	—
6. Kuhlman Selzaete, France	1942	Phosphogypsum	130,000 in 1951 200,000 in 1958	Krystal, double Krystal, triple	Kuhlman
7. Sindri Fertilizers and Chemicals Sindri, India	1947	Gypsum	300,000	Krystal, triple	Chemico and ICI
8. Pakistan Industrial Development Daud Khel, Pakistan	1957	Gypsum	100,000	Krystal, double	ONIA and SPECHEM
9. Fertilizers and Chemicals Travancore Limited	1947	Gypsum plus NH_3 and H_2SO_4	50,000	Krystal, single	Intercontinent Corp.
Kerala, India	1966	Phosphogypsum	100,000	Krystal, triple	--
10. Gujarat State Fertilizers India	Under construction, 1966	Phosphogypsum	33,000	—	Hitachi Zosen
11. Tohoku Fertilizers Akita, Japan	1956	Phosphogypsum	10,000	—	—
12. OSAG (Oesterriche Stickstoffwerke) Linz, Austria	1957	Gypsum	45,000 150,000	Krystal, triple Lurgi	OSAG
13. ANIC Ravenna, Italy	1958	Gypsum	300,000	Krystal, triple	Chemico and ICI
14. Azot Sanayii Turkey	Under construction, 1960	Gypsum	100,000	Krystal, triple	BASF
15. Fertilizers and Chemicals Travancore Ltd. India	1960	Phosphogypsum	25,000	—	—
16. Fertilizers and Chemicals Travancore Ltd.	Later than 1960	Phosphogypsum	110,000	—	—
17. Baroda (Farmers' Cooperative with Japanese Assistance)	1967	Phosphogypsum	155,000	—	—

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*1 metric ton = 1.1 tons

disadvantage in using by-product gypsum is the grayish color of the final product; this is especially a factor in gypsum wallboard marketing. All of these adverse effects (except discoloration) can be reduced to some extent by pretreatment of the phosphogypsum with lime.

The problem can also be approached by examining the process used in the phosphoric acid manufacture. There are more disadvantages associated with the by-product gypsum from the dihydrate process than with the hemihydrate/ dihydrate process because the former contains greater concentrations of phosphate and fluorine impurities (refer to Table 8-3). The phosphogypsum from the two-stage process can be used in plaster and cement manufacture and requires only a water wash treatment and sometimes a lime water neutralization (MU-060). The dihydrate process by-product, on the other hand, must first be calcined to hemihydrate and soluble anhydrite, then neutralized with lime water to yield insoluble, inactive calcium salts. There are several different processes for manufacturing plaster-type commercial products from phosphogypsum. Details are available in the literature (SC-150, EL-039).

8.4 Case Study - Phosphogypsum Disposal

The case studied is typical of the U. S. phosphate fertilizer industry's practices for disposing of by-product gypsum from phosphoric acid manufacture. Mobil Chemical's facilities in Polk County, Florida, were visited by Radian personnel to obtain first-hand information in this subject area.

The acid-contaminated gypsum was being handled by ponding and storing indefinitely. The pond started out as a standard unlined pond receiving gypsum pumped at 30% solids. It is pumped to the top of the pile where, as the material settles, a small dragline constantly dredges it from the center outward. This process results in the walls being built up higher and higher as the dragline "walks" around the perimeter. The piles in the area were cometimes as high as 30 meters and more than 1.6 kilometers in length.

Pollution control measures employed at these facilities included drainage ditches to collect runoff. The collected water is returned to slurry more gypsum. Each plant is equipped with a lime treatment facility to neutralize acidity in the excess drainage. Fluorides in the effluent are controlled by a two-stage lime process.

Some monitoring of local surface water is being carried out; groundwater is not being monitored, however. While release of some slurry liquor to the environment is almost inevitable, no data are available from the industry to ascertain whether or not an environmental hazard exists. No incidents have been detected by state or Federal agencies.

The future of these gypsum piles remains undertemined. The industry is promoting investigation of potential utilization of this by-product. To date, however, no schemes appear commercially feasible.

9.0 ACID MINE DRAINAGE SLUDGE

Acid mine drainage is a significant environmental problem of the mining industry, especially coal mining. This water pollution results when naturally occurring pyrite, FeS_2, in the coal seam and wastes is oxidized in the presence of air and water to form sulfuric acid and soluble iron [Fe(II) and Fe(III)] sulfates. Such mine drainage (AMD) is typically very acidic (pH 2 to 3) and must be treated for pH and dissolved iron before release to surrounding water courses.

Most treatment processes involve four steps:

- neutralization,
- aeration,
- sedimentation of precipitated solids, and
- sludge disposal.

Further details of these processes are available in the literature (CO-122, CO-121, HI-065, ST-149, KO-107, RE-074). Neutralizing reagents commonly used are lime, hydrated lime, or limestone, although sometimes sodium hydroxide or sodium carbonate is employed. The oxidation step converts the ferrous ion to the ferric state which precipitates more readily at a lower pH. Sedimentation traditionally is allowed to take place in lagoons which are also used as sludge storage areas. More recently other means of settling, dewatering, and disposal of the 1% solids sludge are being tested. These developing technologies are discussed in the following subsections of this report following a brief description of the nature of this waste.

9.1 Nature of AMD Sludge

Sludges resulting from the neutralization of acid mine drainage are typically non-uniform and vary widely in composition depending on the make-up of the drainage and the treatment process and reagents. The Office of Coal Research is currently funding a project to investigate the chemical nature of AMD sludges (US-055) an estimated 8.2 million metric tons of sludge (1-5% solids) are produced annually (HI-074).

Most treatment processes aim at achieving a high degree of iron oxidation to promote greater stability and less pollution potential (LO-076). Hydrated oxides of both iron (II) and iron (III) as well as aluminum are always present in varying amounts. The sulfate content also varies widely. Additional constituents include alkalies, silica, manganese salts, calcium sulfate, etc. A typical analysis of solids from an AMD treatment process is presented in Table 9-1. These data are from some preliminary results of the OCR project (US-055). The type of neutralization process was not identified.

The precipitation chemistry of the iron system has an extensive effect on the composition of sludge and on its settling properties. Both ferrous and ferric salts will begin to precipitate at pH 4 or 4.5, but the solubilities are still relatively high in this range. Iron (III) reaches its minimum solubility at pH 6-7, while the ferrous form does not reach its minimum until a much more alkaline range

TABLE 9-1

AMD TREATMENT PROCESS AERATOR SLURRY ANALYSES (US-055)

	Concentration
Slurry water	99.83
Filterable solids (percent)[1]	.17
Solids analysis (percent):	
Fe	10.9
Ca	43.5
Mg	.4
Al	.6
Si	1.6
$SO_4^=$	14.4

---

[1] The weight of aerator slurry retained on laboratory filter paper as a percent of the total slurry.

(8.5-9.5) (LO-076, DA-077). Initial aluminum concentrations in the drainage waters can vary from traces to amounts greater than the iron content. Aluminum salt precipitation has not been investigated as thoroughly as the iron system, although it is known that coprecipitation with iron salts occurs (LO-076). Thus, removal of iron salts from solution by the neutralization treatments also effectively removes soluble aluminum as long as the pH is not raised significantly above 6. Above this point, aluminum salts will be subject to dissolution because of the amphoteric nature of this element.

The physical properties of greatest interest in an investigation of AMD sludge disposal are the settling characteristics. These have been shown to be a function of the neutralization reagent, pH, and the iron oxidation state. The results of one study, as summarized by Lovell (LO-076), ranked various neutralizing reagents on the basis of resultant sludge settleability as follows:

Decreasing Settleability ↓

Na_2CO_3

$CaCO_3$

NaOH

CaO

$Ca(OH)_2$

In another investigation the measured sedimentation and compression velocities of sludge resulting from Na_2CO_3

treatment were 5.28 and 0.218 cm/min., (2.08 and 0.086 in./min.), respectively. Reagents were ranked with respect to settling rates as follows:

Decreasing Settling Rate ↓

limestone ($CaCO_3$)
sodium carbonate (Na_2CO_3)
milk of lime [$Ca(OH)_2$]
caustic soda ($NaOH$)

The general conclusions drawn were that carbonate reagents yield more granular, dense sludges compared to hydroxide additives which tend to produce gelatinous, voluminous flocs.

Lime-treated sludges (pH=6) containing all iron in its +3 oxidation state were reported to settle with a clearly defined interface between settled solids and supernatant; the supernatant was described as very clear. On the other hand, a cloudy supernatant is produced under conditions of incomplete iron oxidation or low pH. With limestone-treated samples, settling during the intermediate period seems slower than with lime neutralization; however, the overall settling rate is actually faster.

9.2 Disposal Techniques for AMD Sludge

Traditionally, AMD sludge is disposed of by pumping the low solids waste to lagoons where it eventually settles to some extent. The lagoon also serves as an ultimate storage site. The problems inherent in this system are the vast land requirements, the potential danger of mass slippage, and release of suspended solids to surrounding water courses if the lagoon becomes full. Therefore, to relieve these problems, the approach has been to develop effective, economical dewatering techniques to reduce storage volume required and to enhance solids settling. This section presents brief descriptions of the current state of technology in the following areas: sludge conditioning; dewatering; handling; and disposal sites. In Section 9.3 alternate approaches to disposal of typical AMD sludge will be discussed.

9.2.1 AMD Sludge Conditioning

Sludge conditioning means treating a sludge in such a way as to enhance the dewatering rate; a conditioning step is not a dewatering step in itself.

There are two basic types: chemical and physical. One example of a physical conditioning process is thickening. This term implies reduction in volume of sludge to be handled in contrast to sedimentation which is basically a water clarification function. There are two mechanisms by which thickening takes place: gravity and mechanical. Typical results of solids increase in thickener clarifiers were summarized by Lovell (LO-076). Again, the results varied with the type of neutralization process. Clarifier underflow from a pilot-scale hydrated lime process ranged from 0.9 to 4.98% solids. Better results were achieved in a limestone system, although quantitative results were not given; a "rather dense mass" was obtained.

The best thickening results were from a limestone sludge neutralized to pH 6.0-7.5. This sludge volume occupied only one-fourth the volume occupied by the hydrated lime-treated sludge. The solids content was 12%; this can be compared with a density of only 1.2% characteristic of a lime process sludge.

Another type of conditioning is chemical conditioning. This entails addition of a coagulant and/or flocculant which promotes destabilization and aggregation of the dispersed material. In general, chemical conditioning improves the settling rate of the sludge, but the percent solids achieved is not affected.

Other conditioning steps for sludge dewatering as reviewed by Moss include the following (WE-078):

- freezing,
- ultrasonic,
- heating,
- artificial seeding, and
- miscellaneous processes.

Many of these were investigated to some extent in Germany during the 1950's by Rummel (RU-030). To summarize his and other's results, freezing was found to be effective in achieving up to 7.5% solids; however, the high costs involved prevented Rummel from following through in that area. More recently, this method is now being studied by the Scientific Control Group of the National Coal Board.

Ultrasonic conditioning, which was proposed as an aid in the coagulation of hydrous iron (III) oxide, actually caused dispersion of that precipitate in two separate studies. Heating was investigated by Rummel with no positive results. Artificial seeding which involves introduction of a material which acts as a nucleation site for precipitate growth is currently applied in several treatment processes as a sludge recycle procedure. These results are discussed in more detail in Section 9.3.

9.2.2 Dewatering Techniques

The most promising dewatering technique for AMD sludge is vacuum filtration; in many cases filter aids have been shown to greatly enhance this method (WE-078, DA-077, LO-076). Vacuum filtration of lime-treated AMD sludge and limestone-treated sludge, in the absence of filter aids, produced up to 29.8 and 45% solids filter cakes, respectively. Filter aids serve to increase the porosity of the cake and thus increase the flow rate. They have been applied both directly to the sludge itself as an additive and as a precoat on the filter surface. Mixed results employing bituminous coal as an additive were obtained. The use of diatomaceous earth as a precoat, however, produced excellent results in terms of % solids achieved. AMD treated with hydrated lime, limestone plus lime, and limestone were dewatered to 22, 45, and 63% solids, respectively.

Porous bed drying is a dewatering technique commonly applied to other types of sludges although experience with AMD sludge is limited (WE-078). Bed materials which are used include natural silica sand, crushed anthracite, crushed magnetite, and garnet sands. This dewatering process occurs in two phases: drainage and evaporation. Yeh and Jenkins determined the filter area requirement to achieve 20% solids of a lime neutralized AMD sludge, initially 1% solids in a bench-scale investigation (YE-005). On a larger scale at the Hollywood, Pennsylvania, demonstration site a three-sectioned bed was constructed on a compacted clay base. The filter bed itself consists of a 0.6-meter (2-feet) layer of red dog with a 5-cm (2-inch) cover of sand. A tile drainage system collects the percolate. One of the three sections is open to the air, a second is covered with plastic except at the ends, and the third is equipped with a close-fitting cover (solar dome effect). The results of these studies have recently been published (LO-080).

Pressure filtration is a technique very seldom used in the United States because of the high expense associated with batch-wise processes. However, considerable experience has been gained in England and other European countries. Rummel's experiments with this dewatering technique were of limited success (RU-030). An aged sludge (1.2% solids) was dewatered to 20-30% solids with the aid of a pre-conditioner. The general conclusion reached, however, was that its low capacity, i.e., filter rate, did not warrant further investigation.

A pressure filtration device of sorts which has been tested on bench- and pilot-scales was described at a recent symposium on coal mine drainage (PA-122). A 25% solids underflow can be obtained; every 20-30 minutes a downtime of 20 seconds was required to operate the batchwise process.

Other dewatering methods that either have not yet been tested or have shown poor capability with AMD sludge include centrifugation, thermal drying, screening, and flotation. Further details are available in the literature (WE-078). Lagooning which can also be considered a dewatering technique is discussed as an ultimate disposal technique under Section 9.2.4.

9.2.3 Sludge Handling

Transport of AMD sludge from the dewatering device to the ultimate disposal site is accomplished by either piping or trucking. Several different piping systems are in use although detailed descriptions of these are not available in the literature.

One system utilizes a portable centrifugal pump located on the sides of the dewatering lagoon. A hose must be manually positioned in the sludge to operate the system. There are a number of disadvantages associated with this practice:

- high labor cost,
- manually difficult job,

- pumping speed partially controlled by sludge flowability toward pump suction,
- "rat-holing" often occurs when the supernatant flows faster than the settled sludge.

A different system employs a pontoon-mounted pump to achieve better accessibility. Other movable pump set-ups are also available.

9.2.4 Ultimate Sludge Disposal

The majority of AMD neutralization plants dispose of their partially dewatered sludges in lagoons where natural evaporation, freezing, and percolation further reduce the water content although failure to drain off supernatant seriously reduces the effects of these natural processes. The volume requirements for a ponding arrangement depend primarily on the extent of dewatering achieved prior to ultimate disposal. For example, a 5-6% solids sludge would require approximately one-third the volume of drainage water treated. After an extended period in a primary settling pond, the resultant 13.9% solids requires only 3% of the volume of drainage treated. For a plant treating water at a rate of 13.6 liters/sec. for 16 hours per day, five days per week (∿200,000 liters or 52,000,000 gallons per year), approximately 0.5 hectare-meters/year (4 acre-feet/year) are required (WE-078). The sludge will continue to settle and compact until equilibrium is reached; i.e., when the weight of solids equals the strength of the flocs.

There is an increasing use of abandoned or inactive deep mines as sludge disposal sites (WE-078, ST-149). The waste is either trucked or piped to boreholes through which it is injected. The alkaline sludge reportedly remains in solid form; also, little resuspension of dissolved solids occurs. These areas require further investigation, however.

To dispose of dewatered sludge on the land as a solid, the following land requirements were given (DE-092). A 2.5-cm (1-inch) layer occupying 0.4 hectare (one acre) will be sufficient for the sludge generated by lime neutralization of 15 million liters (4 million gallons) of drainage each year. Land disposal, however, is infrequently used in comparison to lagooning and deep mine disposal.

9.3 Alternate Approaches

Several variations of conventional neutralization treatments have been proposed, tested, and applied on industrial level. One modification is based on sludge recycling (HI-065). At $\text{pH} < 4$, the rates of coagulation and settling of ferric sludge were low, but could be increased significantly by recycling of previously precipitated sludge to promote growth of better settling particles. At $\text{pH} > 4$, sludge recycle had no effect on settling and coagulation rates which were much higher than in low pH ranges.

The High Density Sludge (HDS) Process was developed and tested by Bethlehem Steel Corp. (KO-107, KO-109). This is a modified lime neutralization treatment which differs from the basic process in the following ways:

- controlled sludge recycle
- recycled sludge is mixed with lime slurry in a reaction tank ahead of the neutralization and separation steps
- iron oxidation state desired is the ferrous (unoxidized) state

Early bench-scale studies produced sludges with at least 40% solids. However, pilot-scale tests were disappointing in that only 15% solids could be achieved; only 30% of the iron was in the ferrous state. Subsequent bench-scale tests developed basic technology that made 30-35% solids possible in a demonstration-scale test which operated for over 2.5 years. A full-scale application has been planned.

A modified version of limestone neutralization is based on production of a well-settling, dense, magnetic form of ferrous sludge. Details of the process are available in the literature (BI-014). The settled sludge volume was reduced by five compared to conventional lime treatment; the corresponding solids content was ~6 times greater.

Potential utilization of this waste material has been investigated to some extent, but so far results have not been practical. Moss has reviewed the major areas of potential commercial utilization of AMD sludge (WE-078). The chief categories are:

- soil conditioning agent, especially for strip mine spoil reclamation,
- additive for building material industry,
- recovery of iron for use as component of blast furnace feed,
- application of gypsum technology, and
- separation of major chemical components by wet sieving.

Greenhouse studies showed that mixtures of mine spoil, AMD sludge, and sewage sludge (45, 25, 30%) promoted plant growth (YE-005). Results obtained were better than those obtained with sewage sludge alone. The Bureau of Mines has tested sludge as a soil conditioner for culm pile reclamation (see Section 5.4).

Since the sludge does not possess cementitious properties, it cannot be used in cement manufacture or concrete technology. However, it may be feasible to use for improvement of color and texture of various building materials. The Office of Coal Research is investigating its potential use as a rock-dust substitute in coal mines because of its high iron, low silica content (US-055).

9.4 Case Studies - Consolidation Coal Company

Consolidation Coal Company mines coal in seven states and currently operates 19 acid mine drainage treatment plants. Their first facility went on stream in 1967 in southwestern Pennsylvania. Since then, additional plants have been built in Ohio and West Virginia as well as Pennsylvania. Three of these facilities located in West Virginia were visited by Radian personnel during the course of this study. Case studies for these are presented below.

9.4.1 Whetstone Portal Treatment Plant

The Whetstone plant went on line in late 1971 to treat acid mine drainage from the Four States Mine (CO-169). This drainage is characterized as low pH, high acidity, and large concentrations of iron and other dissolved metals. Typical chemical analyses of the raw and treated water are presented in Table 9-2 (LO-079).

The main feature of this facility is its simplicity, designed to reduce operating problems. Basically, it consists of a lime slurry mix tank, flash mix tank, aeration unit, and sludge pond. Water is treated at a rate of 250 gpm (16 liters/sec). The hydrated lime is removed from a 40-ton bin by a vibrator system and slurried with water in a 400-gallon (1500-liter) mix tank. The slurry and drainage are contacted in a 2500-gallon (10,000-liter) flash mix tank from which the neutralized drainage then flows to a forced aeration unit of 100,000 gallon (40,000 liters) capacity. Oxidation of iron (II) to the iron (III) form which is less soluble in the treated pH range, occurs here. The sludge then goes to an earthen impoundment where the solids settle and clarified water is pumped to a stream.

Construction of this impoundment was a major undertaking; a 14 meter high earth-filled dam was constructed to retain the sludge. At present, the sludge is estimated

TABLE 9-2

CHEMICAL ANALYSES OF RAW AND TREATED WHETSTONE DRAINAGE (LO-079)

	Raw	Treated
pH	2.4	7.6
Acidity, ppm $CaCO_3$	5400	0
Total Alkalinity, ppm $CaCO_3$	0	59
Ferrous Iron, ppm	1080	<0.1
Total Iron, ppm	1500	0.5
Aluminum, ppm	310	>0.1
Calcium, ppm	550	750
Sulfate, ppm SO_4	8400	2050

to be 4 meters deep in the lagoon. The total capacity of the pond is 55 million gallons (210 million liters). This feature accounted for almost two-thirds of the capital investment. The total cost was $150,000 which included $25,000-30,000 for the lime slurrying and mixing equipment and $35,000 for the aeration unit. Most of the remaining cost was for dam construction. A pH control system was originally installed on the unit, but has been removed because gypsum scaling on the electrodes resulted in ineffective operation. This scale also forms on the shaft and walls of the mixing chamber, aerator, and inner walls of all piping. The scale problem is a direct result of the reduction in sulfate value of the raw water by the system. The resultant calcium sulfate is very insoluble, and precipitates rapidly on equipment surfaces, as the dihydrate, causing scale. Within 4 to 5 months, the scale can build up to 20 centimeters in thickness. Consequently, part of the routine maintenance consists of chipping away built-up scale from all the equipment. This normally requires two or three days of plant down-time. Chemical additives were investigated to determine their effectiveness in preventing or inhibiting scale formation. Those included were long-chained polymers, coagulant aids, and sequestering agents. Results were not completely successful; therefore the approach now being employed is to maintain simplicity in design of equipment.

The effluent from each of the treatment plants discussed here is monitored on a weekly basis using grab sampling techniques, as required by the state of West Virginia. Proposed Federal EPA effluent limitations for the coal industry are:

pH	6-9
Total iron, mg/ℓ	4.0
Alkalinity, mg/ℓ CaCO	> acidity
Suspended solids, mg/ℓ	30

West Virginia requires that the total iron concentration not exceed 10 ppm and that pH be within the 5.5-9 range. Lime neutralization treatment of acid mine drainage is effective in achieving these limits under normal conditions.

9.4.2 Edgell Treatment Plant

The Mountaineer Division of Consol built and operates a lime treatment plant near Wyatt, West Virginia, to treat acid drainage from the western end of the Williams Mine (AK-006, CO-169). This facility handles 5.7 million liters per day (1.5 million gallons per day) of relatively neutral, ferrous-containing drainage. Table 9-3 presents an analysis of the raw water, including high, low, and mean values. Also included is an analysis of the treated slurry.

The system operates by automatic addition of hydrated lime to the slurry mix tank. A pH controller can be used effectively in this case. The lime consumption rate is 218 kg/hour (480 lb/hour). Untreated drainage is used as the makeup water which, upon addition of the lime, turns a charcoal or dark green color indicating the presence of ferrous iron. The lime slurry contacts the bulk of the drainage in a mixing tank; treatment pH ranges from 8.0 to 8.4. The effluent from this tank flows by gravity to an earthen aerating lagoon equipped with a 15 horsepower surface aerator. Two open ditch outlets lead from this unit downhill to the settling pond. The sludge is retained

Table 9-3

Edgell Treatment Plant Chemical Analysis (AK-006)

Analysis of Raw Water

	High	Low	Mean
pH	6.7	4.6	6.0*
Ca (ppm)	480	280	370
Mg (ppm)	150	75	95
Al (ppm)	50	2	20
Si (ppm)	25	5	15
$SO_4^{=}$ (ppm)	5,900	4,100	4,800
Fe^{++} ppm	870	210	460
Fe^{+++} ppm	80	0	30
Total Fe (ppm)	870	220	490
Acidity (ppm $CaCO_3$)	1,700	50	660
HCO_3^- (ppm $CaCO_3$)	440	0	110

Analysis of Slurry

	High	Low	Mean
Ca (ppm)	1,400	620	920
Mg (ppm)	80	70	75
Al (ppm)	75	8	35
Si (ppm)	20	9	15
$SO_4^{=}$ (ppm)	4,300	4,200	4,200
Total Fe (ppm)	340	220	260
Nonfilterable Solids (ppm)	3,100	760	2,200

---

*Median Value

by a dam ∿6 meters high. Approximately 4 meters of sludge have accumulated since start-up in 1970. An estimated 6-7 years of capacity remains. As at Whetstone, clarified supernatant is released to a nearby stream.

9.4.3 Levi Moore Treatment Plant

This facility neutralizes 2.6 million liters per day (700,000 gallons per day) of drainage from the Williams Mine; the plant is located in Harrison County near the coal preparation plan. An important feature of this particular system is its adaptability to either acid or alkaline drainage (CO-169).

Incoming drainage is pumped at a rate of 32 liters per second (500 gallons per minute) and then drops 30 meters to a holding pond. From here the water flows through a metal pipe down the side of a hill, across a set of railroad tracks, and over Bingamon Creek before it reaches the lime treatment unit. Again, forced air oxidation is employed to convert the ferrous iron to the ferric state. The effluent is fed to one of two settling ponds from which clarified supernatant is released to Bingamon Creek.

At the present time, a "desludging" operation is underway. One of the settling ponds is being emptied so that it may be reused. A rake-type stirring device has been mounted on a raft capable of moving along the surface of the pond. The sludge is pumped out of the pond as it is being stirred. The stirring is necessary to prevent "ratholing", which occurs when the liquid flows at a faster rate than the solids. Consequently, only the water is being pumped and the solids remain behind. In this desludging operation, the ultimate disposal site for the sludge is located up the creek bed at a much higher elevation than the settling ponds. At the time of the visit, this project was just getting underway.

This facility formerly housed a pilot plant in which microbiological oxidation of ferrous iron was tested. The system would have allowed use of the much cheaper reactant, limestone, instead of lime following iron oxidation. However, the tests were discontinued because of problems encountered with the bacteria's inability to withstand temperature deviations from 25°C.

10.0 COAL ASH

Coal-fired utilities generate three types of coal waste. Fly ash accounts for the major tonnages, while dry bottom ash and boiler slag contribute lesser but still appreciable amounts. The disposal technologies employed for these by-products were investigated by Radian Corporation for EPA under Contract No. 68-01-2008. This is a summary of much of the information collected during that contract.

Approximately 10-25% of the ash formed during combustion of pulverized coal drops to the furnace bottom and is collected as boiler slag or dry bottom ash, depending on furnace type. The fly ash is suspended in the flue gas stream and collected either mechanically or by electrostatic precipitators. A considerable amount of ash is produced each year and forecast figures shown in Table 10-1 indicate increasing annual tonnages. In 1971, 38.9 million metric tons of coal ash were produced (BR-118). Thus the disposal problem has become critical in some areas. In the past fly ash was either ponded or dumped in a landfill disposal site. More recently effort has been directed toward development of technically and economically feasible utilization schemes, although ponding and landfill remain the prime methods of disposal.

10.1 Nature of Coal Ash

10.1.1 Properties

Chemical analyses of fly ash have shown a high degree of fluctuation in concentrations of major and minor constituents. This is a result of several factors:

TABLE 10-1

CURRENT AND FORECAST ASH PRODUCTION*

	1969	1975	1980
Fly Ash	20	26	33
Bottom Ash + Boiler Slag	10	--	15

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*Units are million metric tons.
Source: LI-051

- variability of original coal composition, even from the same field,
- degree of pulverization,
- type of furnace,
- firing temperature and other operating parameters.

Table 10-2 gives a range of compositions of major and minor species that might be encountered in average ash samples. The basic data are from unspecified Government publications. The uranium and thorium values represent Eastern coals only. Silica and alumina together usually account for more than 70% by weight of the total fly ash sample, especially in hard coal (ER-013). The unburned carbon content is particularly variable, strongly dependent on the operating parameters and combustion efficiency. The high boron content is of special interest since this phytotoxic element could potentially create an environmental hazard.

In Table 10-3 the composition of ashes collected by mechanical and electrostatic precipitators are compared. No significant differences are apparent. These data are from a TVA plant in Alabama. The coal is from Western Kentucky and Northern Alabama, and averages 17% ash.

Release of trace elements to the environment is becoming increasingly a matter of concern. Originating in the coal, a particular element may ultimately wind up either in the fly ash, bottom ash, flue gas as a gaseous species,

TABLE 10-2

POWER PLANT COAL ASH COMPOSITIONS*

Constituent	% by Weight
Silica (SiO_2)	30-50
Alumina (Al_2O_3)	20-30
Ferric Oxide (Fe_2O_3)	10-30
Lime (CaO)	1.5-4.7
Potassium Oxide (K_2O)	1.0-3.0
Magnesia (MgO)	0.5-1.1
Sodium Oxide (Na_2O)	0.4-1.5
Titanium Dioxide (TiO_2)	0.4-1.3
Sulfur Trioxide (SO_3)	0.2-3.2
Carbon (C) and volatiles	0.1-4.0
Boron (B)	0.1-0.6
Phosphorus(P)	0.01-0.3
Uranium (U) and Thorium (Th)	0.0-0.1

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*From RO-093

TABLE 10-3

EFFECT OF COLLECTOR TYPE ON FLY ASH COMPOSITION[*]

	Mechanical Precipitator	Electrostatic Precipitator
% Moisture	0.20	0.30
% Ignition loss	6.60	2.00
% Silica (SiO_2)	51.60	47.50
% Iron (Fe_2O_3)	13.20	16.10
% Alumina (Al_2O_3)	25.00	25.40
% Calcium (CaO)	0.90	1.70
% Magnesium (MgO)	1.10	1.10
% Sulfur trioxide (SO_3)	0.10	0.40
% Available alkalies	0.50	0.40
Specific gravity	2.02	2.14
Blaine fineness (cm^2/gram)	2,250.00	1,900.00
% Passing 200-mesh sieve	88.50	84.70
% Passing 325-mesh sieve	77.80	78.50
Mean particle diameter, microns	13.20	14.80

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[*] From TE-112

or in the system's water. Therefore the trace element composition of the coal has a major impact on the composition of the waste products. Some interesting comparisons for a Western versus Eastern coal can be seen in Table 10-4. Relative to the Western coal, the Eastern coal is very high in zinc, manganese, barium, chromium, and vanadium. The Western coal is higher in arsenic, antimony, selenium, and nickel. It also is interesting to compare the trace element content of fly ash versus bottom ash. Except for manganese and cadmium the fly ash is significantly higher in every element measured.

Generally, 2-5% of fly ash is water-soluble. The resulting solution is usually alkaline due to the effect of free lime (CaO). The principle soluble species are calcium and sulfate ions, with limited amounts of sodium, magnesium, potassium, and silicate also present (BA-169).

One important characteristic of coal fly ash is its pozzolanic activity. A pozzolan is a substance which has no cementing property of its own but develops cementitious properties with lime and water. Some fly ashes possess limited degrees of self-hardening characteristics when moistened and compacted. This phenomenon is partly due to the free lime content of the ash itself, although the results of some studies have indicated that properties of the insoluble portion of the particulate are involved.

The physical properties of fly ash vary with the type of collector employed, moisture content, and firing conditions. A mechanical collector results in a relatively coarse fly ash, the texture of which is described as a fine

TABLE 10-4

SELECTED TRACE ELEMENTS IN COALS AND ASH (ppm)*

Element	Eastern Coal	Western Coal Composite Sample	Fly Ash	Bottom Ash
Arsenic	N.D.	3	15	3
Mercury	<0.01	0.05	0.03	<0.01
Antimony	<0.05	0.17	2.1	0.26
Selenium	N.D.	1.6	18	1
Cadmium	N.D.	<0.5	<0.5	<0.5
Zinc	180	0.56	70	25
Manganese	350	15	150	150
Boron	46	15	300	70
Barium	1800	400	5000	1500
Beryllium	<0.01	N.D.	3	<2
Nickel	N.D.	25	70	15
Chromium	310	5	150	70
Lead	30	4	30	20
Vanadium	180	9	150	70

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*From RO-084

sand. The ash removed by an electrostatic precipitator is much finer, having a silt-like grading. The particle size distribution measured for several Michigan fly ashes, along with several other index properties, are presented in Table 10-5. The range of specific gravities typically reported is 1.9 to 2.4 (BA-169). A small proportion, 1-3%, of the particles are hollow spheres called cenospheres which have an apparent density of 0.4-0.6 g/cm^3. Bulk densities of fly ash vary greatly and maxima are obtained by compaction at optimum water contents.

Engineering properties of fly ash directly affect its potential utilization. Those that are commonly associated with its applicability in structural materials are unconfined compressive strength, shear strength, age hardening behavior, compressibility, settlement behavior, and frost susceptibility. Potential environmental hazards, especially water pollution, can be partially assessed by determining permeability and drainage characteristics. Of special interest is the effect of lime addition, which has been proven to enhance the natural self-hardening characteristics of fly ash through its pozzolanic activity.

Permeabilities of a number of compacted fly ash samples have been determined experimentally. The results ranged from 0.5×10^{-6} cm/sec to 4×10^{-6} cm/sec (RA-084). These indicate anywhere from impervious to medium drainage characteristics, similar to soils having the same particle sizes and gradings.

Compressibility and settling behaviors are other engineering properties of importance. The problem associated with these

TABLE 10-5

PHYSICAL PROPERTIES OF MICHIGAN FLY ASHES*

Property	Sample 1	Sample 2	Sample 3
Specific gravity	2.61	2.48	2.36
Specific surface (cm^2/g)	2620	3050	3050
Maximum dry density (g/cm^3)	1.19	1.45	1.49
Optimum water content (% H_2O)	32.0	23.0	19.5
Particle size distribution:			
> 2mm (gravel size)	0	0	0
0.074-2mm (sand size)	12	6.5	10.5
0.002-0.074mm (silt size)	85	88.5	82.5

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*From GR-087

features is not so much the extent of settling and compaction observed, but rather its predictability. Laboratory results have not always been consistent with field behavior. Untreated fly ash behaves as ordinary soils; aging and loading time intervals have negligible effect. Lime-treated samples experience varying amounts of strain depending on the curing time, or age. Similar behavior is observed under long-term loading.

Bottom ash is the product of coal combustion which collects in the bottom of the furnace or boiler. The nature of this material depends on the boiler type. Modern boilers, which burn pulverized fuel, are usually of the dry bottom type. The heavier ash falls through open grates at the bottom into hoppers which usually contain water. The second type of boiler is the wet bottom variety; the material collected in this equipment is in the molten state and is generally referred to as boiler slag. The proportion of total ash produced by coal-fired utilities categorized as dry bottom ash is approximately 10%.

Chemical analyses are presented in Table 10-6. The results indicate that the major species present in bottom ash are silica (SiO_2), ferric oxide (Fe_2O_3), and alumina (Al_2O_3), with minor amounts of the oxides of calcium (CaO), magnesium (MgO), sodium (Na_2O), potassium (K_2O), and sulfur (SO_3). Trace element compositions of bottom ash were compared to those of fly ash in Table 1o-4.

Boiler slag is a black glassy substance composed of chiefly of angular particles; some of the particles, however, are rod-shaped. The surface texture is porous although not to so great a degree as thatof dry bottom ash. Slags tend to be fairly uniform in grain size distribution, ranging from fine

TABLE 10-6

CHEMICAL ANALYSIS OF BOTTOM ASH (WT. %)

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3
Source #1[*]	53.6	28.3	5.8	0.4	4.2	1.0	0.3	
Source #2[*]	45.9	25.1	14.3	1.4	5.2	0.7	0.3	
Typical Limits[**]	20-60	10-35	5-35	1-20	0.3-4	1-4		0.1-12

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[*] From MO-070 and SE-073

[**] From SE- 075

gravel to fine sand. The specific gravity of boiler slag is typically higher than that of dry bottom ash, but generally varies with the iron content. Chemical analyses of several bituminous slags are presented in Table 10-7. The carbon content, although not reported here, is usually very low (ER-013).

Engineering properties of boiler slags have also been investigated. Because of the more porous nature of dry bottom ash, the optimum moisture contents for slags were found to be lower than values for bottom ash. Permeability measurements were approximately 10^{-6} cm/sec which correspond to typical values for sand. Further details are published in the open literature (MO-070, SE-073).

10.1.2 Quantities

In 1972 a total of 307 million metric tons of coal were burned by the electric utility industry in the United States (BU-087). Assuming a National average ash content of 11% (range 6-20%), this means that 34 million metric tons of ash were produced. Other figures (Table 10-1) show that ash production through 1980 is expected to increase despite predictions of increasing proportions of nuclear power generation (LI-055).

The relative amounts of bottom and fly ash depend on the mode of firing and type of combustion chamber. This is illustrated by the figures in Table 10-8 based on an average coal heating value of 13,700 kJ per pound.

TABLE 10-7

CHEMICAL ANALYSES OF BOILER SLAGS (wt. %)

Ash*	Coal Rank	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	Acid/Base	Source
S-1	Bituminous	49.4	24.8	20.5	10.9	0.8	--	--	7.0	Kentucky
S-2	Bituminous	48.0	18.5	17.9	6.0	0.9	--	--	9.6	Wisconsin
S-3	Bituminous	39.9	22.6	26.3	4.8	1.6	--	--	9.8	New Jersey
S-4	Bituminous	47.4	19.0	24.6	6.7	0.5	--	--	9.2	Indiana
S-5	Lignite	33.8	18.7	6.3	25.2	7.4	--	--	1.6	South Dakota
S-6	Bituminous	45.6	23.8	23.4	3.2	0.7	--	--	17.7	West Virginia
S-7	Bituminous	50.5	25.8	20.1	4.6	0.6	--	--	14.6	Tennessee
S-8	Bituminous	53.1	26.0	20.1	5.5	0.0	--	--	14.3	Ohio
1	Btiuminous	48.9	21.9	14.3	1.4	5.2	0.7	0.1	--	Michigan
2	Bituminous	47.1	28.3	10.7	0.4	5.2	0.8	0.4	--	Michigan
3	Bituminous	53.6	22.7	10.3	1.4	5.2	1.2	0.1	--	Michigan
Typical Limits	--	20-60	10-35	5-35	1-20	0.3-4	1-4		--	--

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*Data for samples S-1 through S-8 were taken from WE-073. Analyses for the Michigan samples were reported in MO-070. Typical limits were published in SE-075.

TABLE 10-8

COMPARISON OF PERCENT FLY ASH FROM DIFFERENT COMBUSTION OPERATIONS*

Type of Operation	Fly Ash (% of Total)
Pulverized Coal Burners	
Dry Bottom, regardless of burner type	85
Wet Bottom, without fly ash reinjection	65
Cyclone Furnaces	10
Spreader Stokers, without fly ash reinjection	65

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*From BU-087

The geographic distribution of coal ash production within the United States is concentrated in the Great Lakes and Midwest regions. The five states of Illinois, Indiana, Michigan, Ohio, and Wisconsin produce more than one-third of the Nation's fly ash (LI-055). Very limited amounts of coal ash are produced in the West. This impacts not only the disposal aspects such as land availability but also the ash utilization market.

10.2 Disposal Technology

Basically there are three alternatives available for the ultimate disposal of solids from fossil fuel fired utilities: ponding, landfill, and utilization. The first two approaches, in which the solids are viewed as throw-away wastes, are discussed below with consideration given to the technical, economic, and environmental aspects of each. Another alternative, deep mine disposal, is also briefly described. Commercial utilization is treated in Section 10.2.4.

10.2.1 Ponding of Coal Ash

Ash ponds are typically operated such that the slurry enters one end of a single pond. As it flows to the opposite side, the well-settling ash drops out and a pool of supernatant forms at the far end. The effluent is removed via weirs or standpipes, thus allowing continuous operation of the pond until full. In ash pond management, the settled ash is seldom used to increase the height of the walls because its spherical form results in a low angle of repose.

In Table 10-9 analyses of ash pond effluent for TVA's Widows Creek operation are presented. Only metal analyses for iron and manganese are given, and these are very low. Total dissolved solids are generally low enough to meet the U.S. Public Health Service limit of 250 mg/l. Table 10-10 presents data on ash pond liquor composition for ten plants in the Ohio Basin Region. Radioactivity data also are presented. Phosphorus, ammonia, and nitrate are all very low in concentration for all plants. Boron is very high for four plants. Regarding the radioactivity, U.S. Public Health Service limits are 3 pci/l (picocuries/ liter) for alpha radiation and 1000 pci/l for gross-beta-activity; some of the pond liquors exceed the alpha limit. Table 10-11 shows results of trace constituents in an unidentified ash pond. Note the low boron concentration compared to the values for the Ohio ponds given in the previous table.

The major factor contributing to selection of this disposal method is land availability. For a 1000 megawatt coal-fired unit over a 20-year lifetime, about 100 hectares would be required for the ash ponded to a 3-meter depth (JO-083). This figure is based on a 12% ash content of coal, an annual production of 261,000 dry metric tons, a water content of 20%, and a packing volume of 0.59 m^3 dry material/metric ton. Ponding is a feasible alternative only if sufficient land is available in close proximity to the utility, preferably on-site.

The economics of this method of ash disposal indicate that the cost per metric ton of solid is in the range $0.55 - 2.20. This figure represents an operating cost which includes transport plus pond management expenses.

TABLE 10-9

CHEMICAL ANALYSES OF ASH POND DISCHARGE FROM TVA'S WIDOWS CREEK

			Concentration, ppm											
Type of Liquor	Sample Identify	pH	Total Solids	Total Dissolved Solids	Alkalinity, Total $CaCO_3$	Total Hardness $CaCO_3$	Ca	Mg	SO_4	Cl	SiO_2	Fe	Mn	Ref.
Ash Pond Discharge	1971 quarterly samples, TVA's Widows Creek	7.3	250	240	54	69	20	4.6	100	21	5.4	0.29	0.44	TE-112
		9.0	190	190	45	99	34	3.4	95	11	4.4	0.42	0.02	
		9.8	210	210	61	130	47	3.7	70	19	6.1	0.27	<0.01	
		9.1	210	210	75	130	45	4.3	60	17	5.6	0.69	0.02	

TABLE 10-10

POLLUTANT CONCENTRATION IN SEVERAL OHIO ASH PONDS

Type of Liquor	Sample Identity	pH	N in NH_3 (ppm)	N in NO_x (ppm)	P (ppm)	B (ppm)	Radioactivity (pci/ℓ) Alpha	Radioactivity (pci/ℓ) Beta	Remarks	Ref.
Ash Pond	Ten plants in Ohio Basin region	see Remarks	0.1	~0.1	0.1	300	1 ± 1	7 ± 2	pH ranged from 6.2 - 11.5. The ash content of the coals ranged from 11 - 23%, with 13% average.	RO-093
			0.1	~0.1	~0.1	1600	0	15 ± 6		
			0.1	~0.1	~0.1	100	0	6 ± 2		
			1.9	~0.1	~0.1	500	0	5 ± 2		
			0.1	~0.1	0.6	<100	4 ± 3	10 ± 4		
			0.1	~0.1	0.2	<100	1 ± 1	14 ± 3		
			~0.1	~0.1	~0.1	<100	~5	78 ± 14		
			0.2	~0.1	0.1	<100	9 ± 4	44 ± 7		
			0.2	~0.1	0.5	<100	~1	9 ± 5		
			0.2	~0.1	0.1	<100	~4	38 ± 11		

TABLE 10-11

TRACE ELEMENT CONCENTRATIONS IN ASH POND LIQUOR[*]

Element	Concentration, ppm
Lead	.01
Antimony	.015
Barium	.07
Manganese	.075
Mercury	<.001
Beryllium	.002
Boron	.5
Nickel	.015
Cadmium	.01
Selenium	.035
Zinc	.03
Arsenic	.01

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[*] From RO-084

Economics associated with transport of power plant wastes to off-site disposal areas have been established by experience with ash disposal. The results of a 1970 nationwide survey of 22 utilities shows that it was costing $0.033-1.21 per metric ton (average of 25 plants, $0.50/metric ton) to sluice ash to the disposal area (TA-040). Those utilities employing trucking services were incurring slightly higher costs ranging from $0.12-1.47 per metric ton or $0.56 per metric ton on the average (10 plants).

The pond construction cost would depend, of course, on the nature of the design; i.e., if liners or other pollution prevention measures are taken. Some approximate cost figures have been estimated for lined ponds (RO-084). Factors influencing the price include size and type of lining required. For a 2-4 hectare pond with no provision for drainage, $12,000 to $50,000 per square hectare is estimated for clay or stabilized pozzolan base lining. The cost of a drained pond fitted with a soil covered plastic liner can be as much as $62,000 to $75,000 per square hectare.

10.2.2 Landfill

A second approach commonly taken by fossil fuel-fired utilities for solids disposal is landfill. This method eliminates the need for long distance hydraulic sluicing systems and on-site ponding facilities. The disposal area may be either on-site or off, again depending on land availability.

The pollution potential of an ash landfill operation is related to the leachate characteristics. To date, no instances of groundwater pollution by disposed ash have been reported. Related studies currently are in progress in which the availability of molybdenum, boron, and other trace elements to plants is being studied. The results of greenhouse studies have shown that application of fly ash to soils does increase the availability of boron, molybdenum, phosphorus, potassium, and zinc (MA-218). Whether or not this constitutes a potential pollution problem regardless of the beneficial results to some plants is not yet conclusive.

The economics of a landfill operation can vary widely depending on the amount of waste to be disposed of, distance to disposal site, type of transport used, and necessary land reclamation steps. In some instances, there may be an additional fee charged by the receiving agency if the site is not utility owned. A typical cost would fall in the range \$0.55-2.20/metric ton. One source reported costs of \$0.88-0.99/metric ton (TO-027). This figure does not include the cost of reclaiming the area - a factor that is now becoming more and more of a public issue. This would add considerably to the cost of the solids disposal.

10.2.3 Deep Mine Disposal

Another possible option available for disposal of fuel ashes, although not under investigation to the same extent as landfill and ponding, involves direct deposit of the waste below the surface in subsurface mines. Deep mine filling has been used for the disposal of power plant ash (TO-027). The ash is sluiced into the mine through boreholes. Normally, gravity is sufficient to create a flow into the mine. Pumps and additional boreholes were provided in case of hole plugging or increased friction losses. A dewatering sump and a settling basin were formed by constructing dams across the mine floor. Overflow from the settling basin flows to the sump from which it is pumped to an above ground basin. Further details are available in the literature (TO-027, HA-158). Investigation of this approach may be worthwhile to those utilities to which abandoned deep mines are available as a potential disposal site.

10.2.4 Coal Ash Utilization

Fly Ash

Progress in the area of fly ash utilization is more advanced than other types of waste utilization because of the greater quantities of fly ash generated compared to bottom ash or slag and the longer period of experience with this material compared to sludge. A number of methods have been developed. Some of these have been successfully practiced in European countries and the United States, although the U.S. lags behind other countries in amounts utilized. In 1969 Britain utilized 42% of its total fly ash production, France 55%, and the U.S. only 9%. In absolute tonnages, Britain and Germany each use more than the United States. More recent figures, however, show that the U.S. is increasing its rate of fly ash utilization, which rose to 12% in 1971 (BR-118). Corresponding increase in total ash utilization for the same year rose to 20.1%. This indicates a need for better market development in this country not only to realize some economic return for the utility industry for their by-product, but also to alleviate possible detrimental environmental aspects of ash disposal.

During the recent Third International Ash Utilization Symposium, information concerning research progress and marketing success in this area was exchanged. The following categories encompass the most pertinent areas in which effort has been expended:

- marketing
- fly ash processing
- extraction of metals
- structural material (highway construction, structural fill, concrete additive, etc.)
- soil additive and conditioner (land reclamation projects and fertilizer)
- miscellaneous uses.

Table 10-12 indicates the quantities of ash types used in various commercial schemes during 1971. Also shown are projected ash production figures for 1976 (BR-118).

There are several general aspects of marketing of fly ash which will determine the feasibility of such an approach. These apply not only to fly ash but other power plant wastes as well. These were presented recently by a marketing company official and, although his remarks were specifically related to its utilization as a pozzolan, they are broad enough to cover all potential uses (HY-011). The following must be assured in order to successfully market fly ash:

TABLE 10-12

ASH COLLECTION AND UTILIZATION, 1971 (Tons*)

	Fly Ash	Bottom Ash	Boiler Slag
Ash uses:			
1. Mixed with raw material before forming cement clinker	104,222	–	91,975
2. Mixed with cement clinker or mixed with pozzolan cement	16,536	–	–
3. Partial replacement of cement in:			
a. Concrete products	177,166	35,377	76,563
b. Structural concrete	185,467	–	–
c. Dams and other mass concrete	71,411	–	–
4. Lightweight aggregate	178,895	13,942	–
5. Fill material for roads, construction sites, etc.	363,385	533,682	2,628,885
6. Stabilizer for road bases, parking areas, etc.	36,939	7,880	49,564
7. Filler in asphalt mix	147,655	2,833	81,700
8. Miscellaneous	98,802	475,417	428,026
Subtotal	1,380,478	1,069,131	3,356,713
Ash removed from plant site (at no cost to utility, but not covered in categories listed above, see Table II below)	1,872,728	542,895	381,775
Total ash utilized	3,253,206	1,612,026	3,738,488
Ash removed to disposal areas (at company expense)	24,497,848	8,446,941	1,232,298
Total ash collected, 1971	27,751,054	10,058,967	4,970,786
Estimated 1976 ash production	36,994,436	117,411,603	2,517.703

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* 1 metric ton = 1.1025 tons (short).

Source: BR-118

- developed utilization scheme,
- distinct technical advantage over other raw materials,
- economically competitive with other raw materials,
- strict quality control,
- consistency,
- uniformity,
- availability.

Electric utilities desiring to place their fly ash on a commercial market have the option of selling it themselves or forming a contractual agreement with an ash marketing firm. The latter alternative offers several advantages which include, among others, removal of legal responsibility for quality control. Disadvantages as well as additional advantages are dealt with by Hyland (HY-011) and Zimmer (ZI-012).

The majority of fly ash utilization occurs in the area of concrete addition, serving both as a mechanical filler (supplementing or replacing fine aggregate) and as a pozzolan (supplementing or partially replacing cement).

A major application in this utilization area is pozzolanic pavement. A great deal of interest has been shown in constructing road base courses of mixtures of fly ash, lime, aggregate, and sometimes cement. Several states including West Virginia, Virginia, Illinois, Maryland, New Jersey, Ohio, and Pennsylvania have specifications for lime-fly ash-aggregate base course. Last year approximately one million tons of fly ash were used in road construction in the Chicago area alone (SL-041).

Several commercial mixes are being marketed basically as stabilized road bases. One of these is Poz-O-Pac developed by what is now I.U. Conversion Systems, Inc., (PU-017). It consists of a small amount of lime, greater amount of fly ash, and the bulk being aggregate. A number of other waste materials can also be incorporated into this basic mixture. The cost is approximately $3.80/metric ton (approx. $3.50/ton).

Fly ash is an approved mineral filler for bituminous or asphaltic concrete; however, application has been limited (FA-058, ZI-012). Technically fly ash performs well in that it provides for increased stability and durability. The characteristics of this by-product important in this application are its hydrophobic properties and good void filling capacity. The economics are based on the availability of low cost competitive mineral fillers such as limestone dust.

Extensive testing of fly ash/water mixtures as load-bearing fill has been reported. Various applications in embankments, road filling, landscaping, grouting, and ash pond dams have been made. In general, fly ash attains much greater strengths than soils normally used in compacted earthworks. Optimum moisture and compaction are very important in this type of utilization. Advantages over alternate fill materials include ease of handling and spreading; light weight; increased compaction strength, cohesion, and angle of shearing resistance with time; and high pozzolanic action (RE-073).

Much of the research and utilization in this area has been done in England where extensive use in highway embankments, especially as fill behind bridge abutments, is made. The results have been excellent with minimal differential settlement between the approach and the structure itself (LA-085).

Several ash ponds have been constructed in Europe using fly ash fill to retain the slurried ash. One at Gale Common, England, will serve as the central disposal site for five generating stations. The dikes which will have a maximum height of 100 feet are constructed of compacted fly ash with no treatment other than dewatering to optimum moisture content. A second pond, located in Eastern France, has been sited in a dammed tributory stream of the Saar River. Dam construction began in 1958 and, as more storage is needed, the dam height is increased. Maximum height will be 120 feet. Compacted layers of fly ash (18-22% water) are used in the construction.

Problems associated with use of fly ash in this application include erosion and liquefaction. Internal erosion is controlled by properly designed drainage and filter system. External erosion is prevented by vegetative cover on the downstream side, slope protection on the upstream side with clay or similar material, and adequate spillway or runoff diversion. Liquefaction, or a sudden decrease in shearing resistance, occurs under the following conditions:

- material gradation typically in range of fine sand to coarse silt,
- loose material with high percentage voids,
- high water table or excess pore water pressure,
- shock loading.

The first two cannot be controlled when fly ash is used. Therefore extreme caution must be taken to prevent water pressure buildup and shock loading.

The Bureau of Mines is actively investigating the use of fly ash in mine subsidence prevention and fire control (SL-041, FA-058, TE-114, MA-247, NA-134). Successful extinguishment of a mine fire in Pennsylvania has been reported. In addition, fire prevention can be achieved by either dry pneumatic injection or slurry injection.

A great deal of effort is being made in the use of fly ash in reclaiming acid mine spoil areas (FA-058, SL-041, AD-015, CA-112, NA-132). In this capacity fly ash serves as a neutralizing agent, a diluting agent, a soil amendment, and enhancer of soil's water retention capacity. The reclaimed soil has been shown to support a number of grasses (Kentucky 31 fescue, rye, red top) and legumes (birdsfoot trefoil) although negligible survival of trees and shrubs has been observed. Reclamation costs depend on terrain, soil type, age, acreage, equipment employed, legislative requirements, and degree of reclamation desired. One source estimated a cost of approximately $740/hectare ($300/acre) for previously leveled land (NA-132). Total costs estimated by another source, however, are in the range $2000-3000/hectare ($800-1300/acre) (CA-112). This figure includes a hauling charge estimate plus the basic reclamation cost ($700-1000/acre for earthmoving, seeding, fertilization, and soil conditioning). The factor which accounts for the large difference in the two estimates is the cost of leveling.

Greenhouse and field experiments have been conducted to determine the availability and possible adverse effects of certain elements in fly ash to plants (FA-058, SL-041, RE-073, MA-218, MA-219, DO-043). Some of the metals of interest include B, K, Zn, Mo, Al, and Mn. Mechanisms involved are also under investigation; pH and kinetics are thought to be strong factors. Results to date indicate that most fly ashes tested do increase soil availability of these species. Utilization as a soil nutrient is limited, however, in that ash does not supply the major plant nutrients such as nitrogen.

Another promising use for sintered fly ash is as a lightweight aggregate. Several processes have been developed for manufacturing fly ash aggregate (BA-169). The product is a hard cellular material with a bulk density of approximately 0.89 g/cm^3 (approx. 50 lb/cu ft) (approx. one-half that of gravel). Although it is not as strong as gravel, strengths are still high enough to have wide applicability, especially as a concrete aggregate (RE-073, TE-114, BA-169).

Manufacture of fly ash bricks is currently on an industrial level. A process developed by the Coal Research Bureau at West Virginia University is utilized by a Canadian manufacturer whose annual production is 35 million bricks. A Czechoslovakian plant is also planned; approximately 91,000 metric tons (100,000 tons) of fly ash will be utilized annually. The process itself is based on a composition of 74% fly ash, 23% boiler slag, and 3% sodium silicate (TE-114). The product is chemically no different from clay-fired bricks, weighs about one-third less than clay bricks, and costs approximately one-third less. Another significant factor is that virtually no seconds are produced in this process (RE-084).

Another utilization area for fly ash is in water treatment and sewage conditioning. The properties of ash which make this use feasible include its absorptive capacity for organic matter, neutralizing properties for acidic media, reactivity with inorganic phosphorus, and particulate characteristics (FA-058, SL-041, TE-114, TE-125, JO-087).

Slag and Dry Bottom Ash

The percentages of boiler slag and dry bottom ash produced in modern utility boilers are not nearly so high as fly ash production figures. Therefore, the actual tonnages to be disposed of are much less. Percentages finding commercial markets have reportedly been greater for the two bottom ashes than for fly ash in recent years (BO-073, BR-118). This is mainly due to their extensive use as road and construction fill. Another potential use is in mineral wool production; this is still under experimental investigation. Many other miscellaneous uses for boiler slag have been investigated (ER-013), but will not be fully described in this report.

Processing of dry bottom ash is not required, at least in the utilization schemes normally employed. Wet bottom ash, or boiler slag, is treated in some cases prior to commercial marketing (ER-013). One processing technique involves screening to achieve uniform particle size. The granules separated by this method show stress-cracking, and the grain structure of this material seldom meets requirements. A second process employs an impingement mill. The product in this case is a gray to black sand having a particle size distribution that meets that specified for sand. All of the granule fractions possess regular cubic form, high strength, and low bulk weight. The material has a high melting point and low heat transfer properties.

One of the best examples of application of slag and bottom ash in road construction is a 9-km long project carried out during 1971-72 in West Virginia. No natural aggregates were used, almost all materials being industrial by-products including approximately 230,000 metric tons of power plant ash and slag (BR-118, MO-070, NA-130). An expected savings in material costs is estimated at approximately $500,000.

Experience in using untreated bottom ash as a base course material was not as successful. If allowed to dry out after compaction in place, it tended to break up. If covered immediately with a surface course, this did not occur. This phenomenon can be prevented by addition of fines such as fly ash (30-40%) or by addition of blast furnace slag to the bottom ash.

The overlying course in the West Virginia Route 2 project was placed in two lifts and compacted to a final thickness of nine inches. The composition was a mixture of 80-85% bottom ash and 15-20% blast furnace slag.

The surface course was a two-inch layer of bituminous concrete containing boiler slag and blast furnace slag as aggregate. This application is now being investigated to determine its skid-resistant and wear-resistant properties (SL-041). It has been reported that boiler slag surfaces show better than average skid-resistance compared to other economically available surface materials (MO-071). This is due to the following characteristics of slag:

- hardness and angularity,
- affinity to asphalt,
- elimination of bleeding and fat spots associated with other aggregates.

Other advantages of using slag in surface course applications include:

- permanent black color achieved;
- when used for shoulders, it offers good color contrast with Portland cement concrete;
- dust free; therefore water absorption is low resulting in less erosion and higher resistance to freeze/thaw damage;

- faster drying roads because of dark color;
- rejects actinic sun rays which damage bitumen;
- blendability with other aggregates permits maximum use of less suitable local aggregate.

10.3 Case Study - Coal Ash Disposal At TVA's Widow Creek

The Widows Creek Steam Plant is located on the north shore of Guntersville Reservoir in Jackson County, Alabama. The complex, which has a total generating capacity of 1978 Mw, cosists of eight boilers fired by pulverized coal. The assigned ratings and hourly coal consumption rates for each unit are shown in Table 10-13.

All eight units are served by the same coal storage area. Total consumption rate at full load is 677 metric tons per hour. Assuming an ash content of 17%, approximately 115 metric tons of ash are produced hourly; 75% of this is estimated to be fly ash. Units 1-6 are equipped with mechanical collectors rated at 70% efficiency. The electrostatic precipitator installed on unit 7 is 99% efficient, but that on unit 8 is only 50-70% efficient. Overall removal on this unit will be increased to 99% when an SO_2 scrubbing system now under construction, goes on stream.

Solid wastes generated at Widows Creek are disposed of by ponding. The original ash pond used for units 1-6, located inside a railroad loop, was filled and taken out of service when the existing pond was put into service in

TABLE 10-13

CAPACITY AND FUEL CONSUMPTION RATES FOR WIDOWS CREEK UNITS

Unit	Start-Up	Capacity, MW	Coal Consumption Rate, metric tons/hour
1	1952	140	53
2	1952	140	53
3	1952	140	53
4	1953	140	53
5	1954	140	48
6	1954	140	48
7	1961	575	185

February of 1961. A portion of the first pond has been vegetated, while the other half is being used as a source of fly ash for mixing with cement.

The pond now in use is located northwest of the plant on the southern shore of Widows Creek Embayment. The 26 hectare (65 acre) area receives ash from all eight units. Ash accumulated in the fly ash hoppers at units 1-6 is transported to the disposal site by a hydroveyor system. Water jets create a vacuum which removes the ash from the hoppers, and the slurry subsequently flows by gravity to the ponds. A similar ash removal system is employed to remove the electrostatically precipitated ash from hoppers on units 7 and 8; however, a pumping system is required to transport the slurry to the pond. The total amounts of fly ash disposed of in fiscal 1970 were:

Units 1-6	137,806 metric tons
Units 7,8	201,948 metric tons

Bottom ash disposal is handled by a separate transport system although it ultimately winds up in the same pond as the fly ash. This waste is washed from hoppers by high velocity sequential jets and the resulting slurry is then pumped to the pond. Clinkers from units 7 and 8 are first ground, then disposed of by this system. In fiscal 1970 units 1-6 generated 65,621 metric tons of bottom ash, and units 7 and 8 produced 82,697 metric tons. Under full load conditions, 236 and 277 metric tons per day are generated daily by units 1-6 and 7,8, respectively.

Other wastes that are discharged from the plant to the pond include pyrites that are rejected from the coal pulverizers, boiler wash solutions, ash slurry sump wastes, air preheater and economizer dusts, coal scale dusts, and residue stack dusts.

The clarified effluent is discharged into Widows Creek Embayment over two spillways located at the southwest and southeast corners of the pond. Eventually it reaches the Tennessee River. The effluent averages 76 million liters per day (20 million gallons per day)of relatively clear, colorless, alkaline water. Several chemical analyses of the ash pond water and discharge are presented in Tables 10-14 and 10-15. The first shows a fairly recent analysis of major and trace components, while Table 10-15 indicates the variation in parameters measured. The discharge is monitored on a weekly and quarterly basis for those parameters indicated in Table 10-16, and continuously for quantities of water released. In addition, daily patrolling and inspection of the area provides added protection against possible failures. Discharges from this pond are in compliance with the Alabama Water Quality Standards for waters used for public water supply. These include a limit for dissolved solids of 500 mg/ℓ.

To date, no significant impact on water quality or aquatic life has been observed. Biological studies of the area in 1968 involved sample collection from the bottom of Widows Creek Embayment near the ash pond outfall. The results indicated relatively abundant fauna both above and below the discharge point. Communities of typical benthic fauna normally associated with fine sediment substrate were

TABLE 10-14

WIDOWS CREEK ASH POND ANALYSES, JANUARY, 1973

Quarter	January
Date	1-8
pH, units	9.2
Phenol. Alkal., mg/l	11
Total Alkal., mg/l	45
Conductive at 25°C umhos/cm	120
Chloride, mg/l	6
Sulfate, mg/l	100
Diss. Solids, mg/l	230
Sus. Solids, mg/l	11
Iron, mg/l	0.90
Manganese, mg/l	<0.01
Ammonia as N, mg/l	0.37
Total Phosphate, mg/l	0.19
Silica as SiO_2, mg/l	5.6
Cyanide, mg/l	<0.01
Copper, mg/l	<0.01
Zinc, mg/l	0.04
Chromium, mg/l	0.009
Aluminum, mg/l	2.1
Nickel, mg/l	<0.05
Silver, mg/l	<0.01
Calcium, mg/l	44
Magnesium, mg/l	3.9
Hardness, mg/l	130
Lead, mg/l	<0.010
Mercury, mg/l	0.0009

TABLE 10-14 Continued

WIDOWS CREEK ASH POND ANALYSES, JANUARY, 1973

Quarter	January
Barium, mg/l	<0.1
Arsenic, mg/l	0.036
Cadmium, mg/l	<0.001
Selenium, mg/l	<0.004
Beryllium, mg/l	<0.01

TABLE 10-15

WIDOWS CREEK STEAM PLANT
ASH POND DISCHARGE ANALYSES

(Quarterly Samples)

Date	Time CT	Temp. °C.	pH	Alkalinity Phen. $CaCO_3$ mg/l	Alkalinity Total $CaCO_3$ mg/l	COD mg/l	Total Hard. $CaCO_3$ mg/l	Ca mg/l	Mg mg/l	Cl mg/l	Na mg/l	Fe, Total mg/l	Mn, Total mg/l	SO_4 mg/l	SiO_2 mg/l	Cond. µmhos/cm	Solids Dis. mg/l	Solids Tot. mg/l
1967																		
10/3	0.745	22.0	--	--	--	8	--	32	4.0	17	10.0	<0.05	0.01	140	3.6	350	--	--
1968																		
4/2	0800	--	--	--	--	--	--	16	3.0	7	6.2	0.05	<0.01	50	<0.1	320	--	--
6/28	1300	--	--	--	--	--	--	23	3.0	9	--	<0.05	--	75	0.8	320	--	--
Sept.	--	--	--	--	--	--	180	60	7.0	27	12.3	0.06	0.01	75	3.1	410	--	280
1969																		
1/29	0800	--	8.7	3	56	--	--	--	--	20	8.0	--	--	130	4.5	470	--	400
4/3	--	--	7.1	0	33	--	110	--	--	--	--	--	--	45	1.3	200	--	210
10/6	--	--	9.7	32	73	--	72	24	3.0	25	--	0.05	<0.01	120	5.8	320	330	350
1970																		
1/5	1000	--	9.4	14	30	--	73	26	2.0	10	--	<0.05	<0.01	110	12.0	270	180	210
4/8	--	--	9.1	14	61	--	100	35	3.0	7	--	0.53	0.01	100	5.3	330	250	270
7/6	--	--	10.1	32	60	--	98	35	2.5	15	--	0.28	0.03	90	6.8	380	280	290
10/7	0830	--	9.8	21	44	--	45	14	2.5	25	--	0.26	<0.01	50	5.2	310	170	180
1971																		
1/4	--	--	7.3	0	54	--	69	20	4.6	21	--	0.29	0.44	100	5.4	360	240	250
4/5	--	--	9.0	6	45	--	99	34	3.4	11	--	0.42	0.02	95	4.4	300	190	190
7/6	0830	--	9.8	52	61	--	130	47	3.7	19	--	0.27	<0.01	70	6.1	290	210	210
10/4	--	--	9.1	25	75	--	130	45	4.3	17	--	0.69	0.02	60	5.6	--	210	210

TABLE 10-16

ANALYSIS OF SAMPLES COLLECTED QUARTERLY WATER QUALITY MONITORING NETWORK

Temperature
Dissolved Oxygen
Coliforms (fecal and total)
pH
Alkalinity
Hardness
Color (true and apparent)
Turbidity
Conductance
Solids, suspended and dissolved
Oxygen demand, biochemical (BOD)
Oxygen demand, chemical (COD)
Nitrogens (organic ammonia, nitrite plus nitrate)
Phosphorus (soluble and total)
Sodium
Potassium
Calcium
Magnesium
Chloride
Fluoride
Sulfate
Silica

Aluminum
Arsenic
Barium
Beryllium
Boron
Cadmium
Cesium
Chromium
Cobalt
Copper
Iron (ferrous, dissolved, and total)
Lithium
Manganese (dissolved and total)
Mercury
Nickel
Selenium
Silver
Strontium
Titanium
Zinc

observed on the Creek and Embayment bottoms. Some fly ash was found, although it did not appear to affect sensitive fauna species. The conclusion reached was that the discharge was "not significantly toxic" (TE-101).

A new disposal area is presently under construction. This project involves relocation of Widows Creek and its embayment. The site totals 93 hectares (230 acres) which will be divided into two areas, one for disposal of all ash from units 1-7 and the precipitator ash from unit 8 and the other for scrubber waste (sludge plus ash) from unit 8. The ultimate storage capacity is designed for 2.4 million cubic meters for ash disposal and an additional 5.0 million cubic meters for unit 8 wastes. Initially, however, the capacities will be much less since periodic dike raisings are planned to gradually increase the capacity.

An impervious dike of compacted earth which will form the perimeter is being constructed; it will connect to the dikes at the east and west sides of the existing ash pond. Material scraped from the interior of the pond will be used. The outer slope will be no steeper than 2.5:1. A minimum of 1.2 meters of freeboard will be allowed. The sludge and ash disposal areas will be separated by a divider dike of similar construction. The pond bottom will be compacted by heavy equipment and, according to TVA design engineers, will become impervious due to early deposition of fly ash (FA-069).

Operation of the new ash pond will be similar to that used for the existing pond and the effluent is likewise expected to be similar in composition. The spillway will discharge to an open channel along the southwest side leading directly to Guntersville Reservoir. The average dilution effect will be much greater than that presently occurring into Widows Creek Embayment, even without diffusers or mixing devices. Closed-loop operation of the scrubber is planned which will eliminate any discharge from the second waste area. The unthickened sludge will be pumped as a 15-16% solids slurry to the pond. A final settled density of 40% solids is expected, based on pilot plant data showing 57-66% water content after 240 days of settling. The overall disposal rate is calculated to be 115 cubic meters per hour.

The same monitoring procedures used for the existing ash pond will be practiced when the new pond goes into service.

11.0 SCRUBBER SLUDGE

The disposal of sulfur-containing sludges generated by lime or limestone wet scrubbing processes is currently under study by EPA and the electric utility industry. Their purpose is to determine the extent of potential problems which may exist with respect to water pollution or land reclamation aspects of scrubber sludge disposal. Several reports describing the current state of knowledge in these areas have been prepared by Radian Corporation under contract numbers 68-02-1319 Task No. 1 and 68-02-0046 Task No. 12. These documents are expected to be released shortly. The information contained in this section summarizes the findings of those investigations.

11.1 Nature of the Material

The environmental impact of any disposed material is a function of its physical and chemical properties and of the quantities involved. Potential water pollution problems can, in many instances, be predicted by chemical properties such as solubility, presence of toxic metals, and pH. Land reclamation is strongly affected by the physical characteristics of the sludge. The load-bearing capacity is especially important in this respect. Section 11.1.1 of the report deals with experimental investigations of properties of sludge and related materials, while Section 11.1.2 outlines the method used to predict amounts expected from scrubbing systems and presents results of the calculations.

11.1.1 Chemical and Physical Properties of Scrubber Sludge

The sulfur compounds produced by flue gas desulfurization systems fall into two general categories: throwaway or saleable products. Lime/limestone scrubbing systems generate a throwaway sludge with little commercial value at the present time. Lime scrubbing processes ordinarily produce sludges containing $CaSO_3 \cdot \frac{1}{2}H_2O$, $Ca(OH)_2$, $CaSO_4 \cdot 2H_2O$ and $CaCO_3$; limestone sludges generally contain $CaSO_3 \cdot \frac{1}{2}H_2O$, $CaSO_4 \cdot 2H_2O$, and $CaCO_3$. For coal-fired installations where efficient particulate removal is not installed upstream of the wet lime/limestone absorber, such sludges can also contain large quantities of coal ash.

From data available to date, it has been found that the exact chemical composition of scrubber sludges varies widely from one system to another, and even within the same system. Therefore it is not possible to give an analysis which truly represents all systems. Factors affecting the final composition include:

- composition of the fuel
- composition of the SO_2-reactant (lime or limestone)
- composition of the make-up water
- operating conditions (e.g., closed- or open-loop operation)

- settling characteristics, i.e., ease of dewatering,
- rewatering of the dried, aged material,
- strength, i.e., load-bearing capability,
- ability to support vegetation growth (chemical properties also are important here).

Viscosity, particle size, Blaine Index, and several other physical parameters have been measured for various sludge materials (SE-066, AE-007, AE-008, AE-009). In addition, it was reported that the bulk densities of various scrubber sludges vary similarly as a function of water content. As the percent of water increases from zero, the bulk density increases as the pore volume becomes filled. When completely filled, a maximum bulk density is reached. With greater percentages of water, a dilution effect is observed as the bulk density decreases. For clarifier underflow samples from EPA's Shawnee limestone scrubbing system with simultaneous fly ash removal, the peak bulk density was reported to be 1.7 g/cm^3 at 30% water content. The bulk density of a packed and dried Shawnee sample was 1.20 g/cm^3. These data are compared to the true density of Shawnee solids equal to 2.48 g/cm^3 (AE-008). The peak bulk density for an individual sludge will depend on the nature of the scrubber system from which it was obtained. For example, the sludge from a western power plant employing a limestone system was shown to have a maximum bulk density of 1.87 g/cm^3 at 22% water content.

Based on preliminary results of experiments designed to study settling properties of scrubber wastes produced by lime/limestone systems, this phenomenon is not expected to result in extensive separations. From a bench-scale experiment conducted by TVA, a settling rate of 5 cm/hour was observed for the first two phases of settling, which were defined as the induction period during which floc formation occurs and the second stage, free settling (SL-034). The third phase is compression settling, i.e., when the flocs begin to touch each other and gel formation occurs. The settling rate during this stage was greatly reduced. After 48 hours the settling rate decreased to practically zero and no further settling was observed, even over a period of several months.

Aerospace reported that limestone sludges with high sulfate content settle to 45% solids with no drainage provided. This is compared to final settled solids content of 50% with underdrainage. Sludges having high sulfite content settle only to 35% solids regardless of whether drainage is provided (RO-084). Dravo Corporation compared solid contents of various power plant wastes after one day of settling. Results obtained with samples from a lime system installed on an Eastern coal-burning facility ranged from less than 30 to 45 weight percent solids. A different lime scrubber sludge sample obtained from a Western coal-burning plant equipped with a fly ash removal system upstream of the scrubber yielded much poorer results - 21.5% solids. Two different limestone scrubbing systems were also sampled. Both samples had no ash present. Results achieved were 37-40% solids. These sludge samples may be compared to ash which was reported to settle to 64% solids under the same experimental conditions.

Settling characteristics of lime/limestone scrubbing sludges are directly related to the degree of compaction. The factors affecting this parameter include the following, all of which are currently under investigation by TVA (SL-034).

- hydraulic head
- ash content
- degree of oxidation
- stirring
- agglomeration
- lime vs. limestone

Results of bench-scale studies indicate that increasing the height of the slurry column increases the degree of compaction. When the height of an experimental column was increased from 13 cm to 100 cm, compacting was increased by 15%. It is predicted that a high ash content in the sludge would also produce favorable effect on settling although no data are available to support this point.

Degree of oxidation is under intensive study. It is known that calcium sulfate crystals, because of their large blocky nature, settle better than the thin plate-like calcium sulfite hemihydrate crystals. Thus, oxidation to sulfate should improve the degree of compaction. It has been reported that a high degree of oxidation is required, however, to produce a noticeable effect. Methods are now under study to promote oxidation of limestone scrubber slurries.

Identification of scrubber conditions that promote agglomeration of sulfite crystals has not been made yet. Some sulfite crystal agglomeration has been noted. Flocculating agents are being investigated to determine their effectiveness in promoting appreciable agglomeration.

11.1.2 Quantity of Sludge Production

The amount of sludge generated by a given plant is a function of the sulfur and ash content of the coal, the mole ratio of additive (i.e., lime or limestone) to SO_2 removal efficiency of the scrubbing system, the ratio of sulfite to sulfate in the sludge, and the percent moisture in the sludge. Table 11-1 lists values of these various sludge parameters for a hypothetical plant representing the National average expected between 1973 and 1980. These values represent a mix of Western and Eastern plants expected in 1980 based on the trends shown by present flue gas desulfurization system orders.

Most of these parameters will vary from one system to another. The sulfur and ash contents of coal are a function of the source of the fuel. The SO_2 removal efficiency will vary from one flue gas desulfurization system to the next as a function of local requirements.

TABLE 11-1

TYPICAL SLUDGE PRODUCTION PARAMETERS

Sludge Production Parameters	National Average*
Coal:	
Sulfur Content	3.0%
Ash Content	12%
Plant:	
Load Factor	73%
Coal Usage	4 kg/kW-hr
Scrubbing System:	
SO_2 Removal Efficiency	85%
Moisture in Sludge	50%
CaO/SO_2(inlet) Mole Ratio	1.0
$CaCO_3/SO_2$(inlet) Mole Ratio	1.2
Sulfite/Sulfate Mole Ratio	9:1

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[*] The values listed as the National average represent a mix of Western and Eastern plants expected in 1980 based on the trends shown by present flue gas desulfurization system orders.

Since unreacted additive is disposed of with the sludge, the stoichiometry of lime or limestone addition, that is, the CaO/SO_2 or $CaCO_3/SO_2$ mole ratios, greatly influences the amount of sludge to be handled. The CaO/SO_2 and $CaCO_3/SO_2$ mole ratios vary from system to system at present but the general trend is toward lower values as operating experience is gained. It is expected that reasonable values for this ratio will be 1.0 and 1.2, respectively.

Other factors influencing the amount of sludge to be handled are the load factor of the plant, the coal use rate, and the mole ratio of sulfite to sulfate in the sludge. The amount of sludge produced by a plant is directly proportional to the number of hours per year that the plant operates and the coal usage of the plant. The 6,400 hr/year and .4 kg/kW-hr (0.88 lb. coal/ kW-hr) values used for those calculations are typical of large modern generating stations (DU-044, SU-031). Obviously if the plant is on line a larger fraction of the year or more coal is required per kW-hr, the amount of sludge produced will increase. The sulfite to sulfate ratio in the sludge effects the weight of the sludge produced as $CaSO_4 \cdot 2H_2O$ is heavier than $CaSO_3 \cdot \frac{1}{2}H_2O$. The ratio assumed in this paper (9:1) is taken from the SOCTAP report (SU-031). However, some system designers are considering trying to completely oxidize the sludge to improve settling characteristics and decrease chemical oxygen demand. If this were done on a widespread basis the weight of dry sludge produced per plant would increase but improved settling characteristics would tend to lower the proportion of water in the sludge. This would enhance solid/liquid separation of the waste and thus reduce costs and possibly land reclamation problems associated with sludge disposal.

Table 11-2 shows the quantities of ash and sludge produced per year by a 1,000 MW coal-fired generating station controlled by lime/limestone flue gas desulfurization systems. These figures represent the National average sludge and ash production statistics.

Using the forecast demand for flue gas desulfurization given in the SOCTAP report (SU-031) and the National average annual sludge production rates per 1,000 MW of controlled generating capacity, the amount of wet ash containing sludge (50% moisture) that will have to be disposed of annually by 1980 is predicted to be 113 million metric tons (125 million tons). This value is based on the assumption that there will be 116,000 MW of generating capacity controlled by 1980 and that 75% of the control will be by lime/limestone scrubbing systems.

11.2 Application of Conventional Disposal Techniques to Scrubber Sludge

Ponding and landfilling provide the major mechanisms of disposal for most solid waste products. In terms of land use and reclamation, these disposal mechanisms have many points of similarity for various industries. Land use for waste disposal may be esthetically objectionable. The wastes could provide varying degrees of surface and groundwater pollution depending on chemical composition, solubilities, and the location, design and operation of the disposal site. For land reclamation, most of the stable wastes will require only a cover material to support vegetation and prevent eventual erosion. However, some wastes are very resistant to dewatering and could reslurry in the pond or landfill.

TABLE 11-2

TYPICAL QUANTITIES OF ASH AND SLUDGE PRODUCED PER YEAR BY A 1000 MW COAL-FIRED GENERATING STATION CONTROLLED WITH LIME/LIMESTONE FLUE GAS DESULFURIZATION SYSTEMS

	National Average
Coal Ash, dry	307,000 metric tons/year
Coal Ash, wet (80% solids)	384,000 metric tons/year
Limestone Sludge, dry*	
$CaSO_3 \cdot \frac{1}{2}H_2O$	264,000 metric tons/year
$CaSO_4 \cdot 2H_2O$	39,000
$CaCO_3$, Unreacted	99,000
TOTAL	402,000 metric tons/year
Limestone Sludge, wet (50% solids)	804,000 metric tons/year
Limestone Sludge, wet (with ash)	1,418,000 metric tons/year
Lime Sludge, dry*	
$CaSO_3 \cdot \frac{1}{2}H_2O$	264,000 metric tons/year
$CaSO_4 \cdot 2H_2O$	39,000
CaO Unreacted	43,000
TOTAL	346,000 metric tons/year
Lime Sludge, wet (50% solids)	692,000 metric tons/year
Lime Sludge, wet (with ash)	1,306,000 metric tons/year

ASSUMPTIONS:

Coal:	3.0% S; 12% Ash
Plant:	6400 hr/yr; .4 Kg Coal/kw-hr
Scrubber:	85% SO_2 Removal 1.0 CaO/SO_2(inlet) Mole Ratio 1.2 $CaCO_3/SO_2$(inlet) Mole Ratio

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* Sulfite/sulfate ratio based on performance of Chemico scrubbing unit at Mitsui Aluminum Co., Japan.

If this is shown to be true, it is likely that fixation will become a necessary practice.

These are the chief methods used by the utility industry to dispose of ash from fuel combustion. Most technology available to date is based on experiences with that material. Technology associated specifically with sludge is just now under development, thus posing a shortage of available information in that respect. The following sections describe the various features of each disposal operation and, on the basis of available data, present the potential impact on water pollution. Land reclamation aspects for both ponding and landfill are dealt with in a single discussion because of the similarity of an abandoned, dried-up pond and a completed landfill.

11.2.1 Ponding

11.2.1.1 Technical Aspects

The start-up and day-to-day operation of a disposal pond involves answering the following questions, as pointed out by Slack and Potts (SL-034).

- Will the pond be operated as a single unit or divided into sections?
- Will the original depth be the limit or can walls be built up using the settled material?

- Will the pond be partially filled with water before operation begins?

- Can the pond be filled to the top of the dike or must some free board be allowed?

The first question is related to the settling characteristics of the material. In the case of a well-settling waste (ash, for example), the pond is typically operated such that the slurry enters one end of the single pond. As it flows to the opposite side, the well-settling solids drop out and a pool of supernatant forms at the far end. The effluent is removed via weirs or standpipes, thus allowing continuous operation of the pond until full. In contrast, waste gypsum from phosphoric acid manufacture is usually ponded in several units. Since the settling characteristics of the waste are poor, one pond is allowed to dry and be emptied while another pond is being filled. Acid mine drainage sludge possesses especially poor settling characteristics. The retention time in the cases studied for this report were on the order of a week to ten days. This provided sufficient time for clarification of the effluent. The sludge layer, however, only achieved a solids content of ~10%. In some cases, acid mine drainage sludge receives preliminary dewatering in a settling pond prior to ultimate disposal in a second pond.

Scrubber sludge has thus far exhibited poor settling characteristics as previously discussed in Section 11.1.1. High sulfite-containing sludges possess worse settling properties than sulfate (gypsum) type sludges, although in comparison to AMD sludge, both are relatively better settling.

Phosphate slime is another example of a poor settling waste traditionally disposed of by ponding. If ponding is employed as the disposal technique for scrubber sludge, it is likely that a multi-unit pond would be most functional. However, it is still unlikely that high sulfite sludges would achieve any great degree of dewatering from ponding alone.

The second question deals with the dimensional stability of the settled material. For some wastes, including phosphogypsum, this property is great enough to permit its use in raising the height of the walls. Preliminary data for untreated scrubber sludges presented in Section 11.1.1 are not yet sufficient to predict whether this type of operation could be successfully applied.

If the scrubber is operated under closed-loop conditions, smooth start-up may necessitate partial filling of the disposal pond before hand. This would provide a source of recycle water at the onset of operation and eliminate the need for additional start-up pumping arrangements. This would produce overall increasing concentrations with respect to composition of liquor associated with solids until steady state is achieved.

Gypsum from phosphoric acid manufacture is disposed of in a closed-loop system. The gypsum is filtered to separate product acid, and the filter cake is reslurried with recycle water for transport to the disposal area.

The amount of freeboard required for any particular pond is chiefly a function of climate. If the area receives large amounts of precipitation during periods when evaporation rate is low, then more freeboard would be necessary than for ponding operations in hot, dry climates. Ponds which lack drainage provisions would also tend to require greater freeboard.

11.2.1.2 Environmental Aspects

Potential hazards associated with contamination of surface and/or groundwaters by sulfur oxide sludges exist in the following areas:

- soluble toxic species (toxic meaning elements which can cause health problems even at very low concentrations),
- chemical oxygen demand due to sulfite,
- excessive total dissolved solids,
- excessive levels of specific species, e.g., sulfate and chloride, not generally thought of as toxic,
- excessive suspended solids.

These could promote problems via leachate and/or runoff routes. Although similar in nature, these routes will be considered separately in the discussion below.

The composition of the leachate formed is a function of several factors including chemical composition of the sludge, pH, solubility of the individual species present, and age of the disposal site. The nature of the leachate expected from untreated sludge can be judged by analysis of liquors associated with scrubber samples, especially clarifier supernatant or scrubber recycle water in closed-loop operation. Since fly ash will be collected and/or disposed of together with the scrubber sludge in many cases, it is likely that many of the potentially leachable elements originate with the ash. Although ash ponds have been in operation for years, there has been little concern with environmental contamination either by high dissolved solids content or by trace element constituents of the pond waters. Both have recently been shown to be present in varying amounts in several ash pond samples. Likewise, this potential source of contamination has not been investigated for other wastes typically disposed of by ponding. This includes taconite tailings, phosphate slimes, AMD sludge, and phosphogypsum. This type of study, if it were available, would prove very useful in determining potential leachate problems due to scrubber sludge disposal.

A disposal pond provides maximum opportunity for contamination of groundwater. Unlike a landfill, the sludge is always saturated with water, and the "head" of liquor in the pond assures a continuous driving force for percolation. Underlying strata will also become saturated, and if an unconfined aquifer exists beneath the pond, the pond site will act as a "recharge" zone for that aquifer. If no unconfined aquifer exists, the pond liquor will continue to seep into the existing strata beneath the pond. Given that an aquifer does exist, the important factors are the rate at which pond liquor permeates into the groundwater and the chemical composition of that liquor as it enters the aquifer; any suspended material will probably be filtered out by the soil. It is also possible that some dissolved species may be removed from the flow by a group of reactions commonly referred to as soil attenuation mechanisms. These include physical adsorption, chemical reaction, and precipitation. Unfortunately, no data are yet available on this important topic for scrubber sludge liquors although it is known that the soil type is significant.

STEAG, a government organization in West Germany, has instrumented a sludge disposal pond for lime scrubber sludge to determine effects on groundwater. This group has been visited and a description of their system obtained. So far their monitoring system has not detected any contamination of the aquifer which is located only about a meter below their unlined pond. However, their observation wells are far enough away from the pond that sufficient time probably has not elapsed for any contamination to reach the wells. Combustion Engineering and Kansas Power and Light are also doing a study of this type, but no results have been released.

Another potential source of water pollution from sludge ponds is overflow of supernatant. Disposal ponds have typically been operated with less than total recycle of pond liquor. The excess liquid has often been permitted to flow into receiving streams with little treatment beyond neutralization, settling, or skimming. In the case of acid mine drainage sludge ponds, this is an inherent feature of the system in that the purpose of treatment is to improve the quality of the contaminated streams by removing excess acidity and iron. Accidental spills have occurred frequently. Newer and more stringent regulations on waste water disposal will likely reduce the practice of overflowing excess liquor into lakes and streams. This will necessitate the use of closed loop (total recycle) operation for scrubber sludge disposal by ponding with treatment of any blowdown streams. Alternatively, blowdown streams might be disposed of via evaporation or disposal in the ocean. This sort of operation, combined with proper site selection, design, and lining of ponds could eliminate contamination of surface or groundwater by ponded scrubber sludge.

Pond linings have been finding greater favor in recent years. In some cases the intent has been to decrease pollution, in other cases the intent has been to avoid loss of water which could be recycled. In many areas, clay, concrete, wood, or metal has been used as a liner. TVA is planning to have an impervious bottom in their new ash pond at Widows Creek; this will be a result of deposition of ash onto the clay bottom. This may prove useful in achieving impervious bottoms in scrubber sludge ponds, particularly in those cases where ash and sludge are to be disposed of together. This would provide a relatively inexpensive means of achieving a lined pond.

Recently synthetic linings are finding increasing usage. These materials have been reviewed in the recent literature (KU-061). At the present time these are used primarily in ponds handling industrial wastes known to be hazardous.

Some approximate cost figures have been estimated for lined ponds (RO-084). Factors influencing the price include size and type of lining required. For a 2-4 square hectare (5-10 acre) pond with no provision for drainage,

$12,000 to $50,000 per hectare ($5,000-20,000/acre) is estimated for clay or stabilized pozzolan base lining. The cost of a drained pond fitted with a soil covered plastic liner can be as much as $62,000 to $75,000 per hectare ($25,000-30,000/acre).

11.2.2 Disposal by Landfill

A second approach to the problem of disposal of waste solids generated by lime or limestone scrubbing systems is landfill. Currently less than 40% of existing or planned installations have adopted this alternative, while approximately 60% have included ponding facilities. Eventually, however, ponding sites may have to be reclaimed. This possibility would necessitate future conversion to a landfill type of operation.

Characterization of lime/limestone scrubber sludge thus far has revealed a nature not readily applicable to untreated landfill disposal. The sludge does not settle or dewater readily, and the results of some experiments have indicated that once dried, the untreated material will reabsorb moisture to its original water content (see Section 3.3). This creates the unattractive possibility of the disposal site becoming a bog. A second aspect of untreated sludge is its leachate characteristics, discussed to some extent in the preceding section. For these reasons, chemical and physical fixation processes have been proposed and are now under investigation. The marketing agents for these fixation techniques claim that conversion to a physically and chemically stable landfill material is possible. In some cases, a saleable by-product can be made.

11.2.2.1 Technical Aspects of Landfilling Sludge

The technology associated with disposal of waste scrubber sludges by landfill operations is currently in the development stage. There are three basic features requiring discussion to accurately describe the current state of knowledge regarding this disposal method: dewatering, fixation, and handling of sludge.

Dewatering Techniques

The object of any sludge dewatering process is to recover the solid content of the sludge in a concentrated form suitable for disposal or further processing. The liquid content is recovered from suspended solids for recirculation within the process or for safe discharge as a processed effluent. There are numerous techniques available for dewatering industrial wastes, many of which have been experimentally and industrially applied to sludges generated by lime or limestone wet scrubbing systems. These were described in detail in the EPA/Radian reports. Table 11-3 summarizes the methods and results.

Comparable studies have been conducted for dewatering acid mine drainage sludge. Bench-scale tests of several processes have produced results indicating that all methods were technically feasible with few exceptions. The energy requirements and economics, however, were very high (AK-006, WE-078). Because of the huge volumes of drainage receiving treatment, it is unlikely that any of the dewatering methods will be applied on a large scale in the near future. Phosphogypsum, on the other hand, is filtered to separate this by-product acid. The filter cake is ∿65-80% solids and must be reslurried prior to transport to the disposal area.

TABLE 11-3

SUMMARY OF SLUDGE DEWATERING TECHNIQUES

METHOD	APPLICATION	SLUDGE	RESULTS	COMMENTS	REFERENCE
Clarification	Currently used as primary dewatering device on full-scale systems.	Various lime and limestone scrubbing system sludges.	Limestone sludges thicken "better" than lime because of coarse unreacted additive present.		SE-066
	Bench-scale	Limestone system sludge.	~20% solids achieved		AE-006
Bed Drying	Bench-scale column studies.	Shawnee limestone system sludge.	Steady state drainage rate was 0.046 cm^3/min. Sludge with "relatively" high sulfate content settled to 50% solids with underdrainage. High sulfite sludges settled only to 35%. Solids under similar conditions.	Air-dried sludge exposed to water regained original moisture (51.7%).	AE-007 AE-008 AE-004
	Demonstration program, Hollywood, Penn.	Acid mine drainage (AMD) neutralization sludge.	Results not available at time of report.		JE-013
Centrifugation	Bench-scale tests.	Various lime-scrubbing system sludges.	47-57% find solids content (original: 19-44%).	Fly ash was present in the samples.	SE-066
	Bench-scale tests (short-term).	Limestone scrubbing system sludge	53-64% solids achieved (feed was 10-29% solids).		SL-034 EL-030
	Full-scale	Chiyoda process sludge (high sulfate/sulfite ratio).	85-90% solids achieved.		SL-034
	Comparative laboratory-scale.	Various limestone system sludges.	Shawnee sludge: solids content increased from 20 to 56%. Mohave sludge: >65% solids achieved.	Although original water content of sludges were similar, better results obtained with Mohave sludge were believed to be due to its lower water content at maximum density.	AE-006 AE-007 AE-010

TABLE 11-3 (Cont.)

Summary of Sludge Dewatering Techniques

METHOD	APPLICATION	SLUDGE	RESULTS	COMMENTS	REFERENCE
Vacuum Filtration	Bench-scale	Limestone Scrubbing system sludges.	~65% solids achieved.		AE-007
	Bench-scale	AMD neutralization sludge.	Solids content increased from 0.6 to 23%.	Problems with cake blocking filter were experienced.	WE-078
	Bench-scale	Pilot plant limestone scrubbing system samples.	55-60% solids content was achieved.	Compare to 38% solids with settling alone. Thixotropic nature of sludge caused filter cake to rewater upon release. Cake cracking in early stages prohibited further dewatering. Removal of cake from filter was difficult.	SL-034 EL-030
	Pilot-scale; in conjunction with clarification.	Double-alkali system (General Motors).	70% solids achieved.		AE-006
	Full-scale; in conjunction with clarification.	Carbide sludge system (Louisville Gas and Electric).	50% solids was achieved.		VA-068
Thermal Drying	Commercial	SO_2/fly ash removal process.	90-95% of original water content (70%) removed; i.e., achievement of 90-95% solids is claimed.		EB-003

Sludge Fixation

Sludge fixation is the chemical and physical stabilization of sludge or sludge/fly ash mixtures. The intent of the processes is to convert the waste to a non-toxic, load-bearing material via chemical reaction and, in some cases, aggregate addition. Chemical fixation of scrubber sludge and related materials is currently under development by several commercial groups including Dravo Corporation, I. U. Conversion Systems, Inc., Chicago Fly Ash, and Chemfix Corporation. Information available regarding the chemical and physical nature of lime/limestone scrubber sludge indicates a need to investigate potential stabilization techniques. Quantitative data describing various properties of scrubber wastes are presented in other sections of this report. Basically, these data seem to indicate a tendency for untreated, dewatered sludge to rewater upon contact with an aqueous environment. In addition, leaching and permeability features of dried sludges pose potential environmental hazards. The ability of proposed fixation techniques to prevent rewatering and leaching from treated sludges is under investigation. The current status of the fixation techniques now being marketed has been described in the EPA/Radian reports, and is summarized here.

I. U. Conversion Systems, Inc., offers several fixation processes based on the pozzolanic reaction between fly ash and lime (MI-084). Poz-O-Pac®, the original process on which sulfur oxide sludge fixation technology was based, has been industrially applied to the stabilization of fly ash for production of structural materials. Poz-O-Tec* is a commercial process for the stabilization of fly ash using sulfur oxide sludges in addition to lime. The chemistry is comparable to that describing Portland cement technology. The product, Sulf-O-Poz®, is primarily a disposal material, but in some instances could be used as a structural material in land reclamation projects, structural embankments, etc. after a couple of weeks of curing (FO-018). Further processing of Sulf-O-Poz® is another alternative; utilization of the treated sludge as synthetic aggregate or road base material is then possible.

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*A service mark owned by I. U. Conversion Systems, Inc.

The tail end process itself can be retrofitted to existing power plant facilities. Application to oil-fired systems is not feasible, however, since availability of fly ash is essential to the process. Conditions of relatively higher pH, as in lime systems compared to limestone, favor the reactions, although both types of scrubber sludges can be treated by the IUCS process (AE-007). To date, this process has not been applied to a flue gas desulfurization system, but extensive bench-scale testing of that application and the fixed product is currently being performed in the IUCS laboratories.

Those factors affecting the cost of this or any fixation process are given below:

- annual tonnages to be handled by the conversion process,
- new boiler installation versus existing facilities,

- the type of equipment selected for fly ash removal - for example, electrostatic precipitators versus wet scrubbers,
- the chemical analysis of coal - sulfur, CaO, and ash contents,
- location of plant - on-site versus off-site,
- transportation costs - to and from conversion plant,
- redundancy factor - duplication of equipment versus emergency holding basins, etc.
- type of scrubber - limestone versus lime,
- acquisition and cost of land, and
- type of end-product selected.

Based on estimates for newly installed plants in the range 1,000 - 2,000 MW, burning coal with 3-4% sulfur and 10-15% ash content, and incorporating a lime scrubbing system, the cost of sludge disposal is estimated to be $1.65 - 2.76 per dry metric ton ($1.50 - $2.50/dry ton) to convert the sludge to a disposable Sulf-O-Poz® material. This includes the cost of chemicals and process services, but no hauling charges, which can be a major factor.

The Chicago Fly Ash Company also markets a sulfur oxides sludge fixation process based on quicklime/fly ash addition (OB-005). They are currently working with Commonwealth Edison and the University of Illinois to dispose of the sludge generated by a limestone wet scrubbing system installed on a 163 megawatt unit at Will County Station (GI-017, GI-030, ST-117, JO-083). The spent scrubber slurry presently receives dewatering treatment by clarification. Possible secondary treatment, vacuum filtration or thermal disc drying, is being considered to reduce the volume of sludge requiring fixation. Clarifier underflow is pumped to a pond, then to a loading station where the additives and sludge are blended to produce a stable landfill material. For every 1,000 kilograms of settled sludge, 100 kilograms of fly ash and 50 kilograms of lime are added. If higher water content is present, the proportion of additives required goes up rapidly (GI-033). The treated sludge (50% solids) is transported by cement truck to an on-site sealed basin about one-half mile away. An off-site location is planned for the future. At the present time, this fixation process results in physical but not chemical stabilization of the sludge (GI-033). The leachate does not meet Illinois water standards which state that any water entering an aquifer cannot be of lower quality than water removed from it.

A Chicago fly ash spokesman quoted a cost of $16.5/metric ton on a dry solid basis for their process (OB-005). Additional economic information associated with this disposal method can be derived from estimated operating and capital investment costs reported by Will County. A utility spokesman has recently estimated the annual costs for the disposal system as 1.1 million dollars in addition to the initial capital investment of 1.7 million dollars (GI-017). The annual cost included a sludge disposal figure of $823,000 which is equivalent to $7.70/ metric ton of sludge (dry basis). Included in the sludge disposal figure are costs for operating the sludge disposal plant, maintenance, hauling, and landfill. Actual costs incurred on this project, however, are reported to be as high as $19/metric ton of dry sludge (GI-033). Costs possibly may be reduced in the future to $13.30/dry metric ton.

Dravo Corporation also offers a chemical fixation process for lime/limestone scrubbing waste products (SE-066). Much of their technology has been developed using sludge samples obtained at a pilot-scale lime scrubber operating at Duquesne Light Company's Phillips Station; sludge from additional sources has also been examined. The testing of their process has involved basic chemical and engineering evaluations of the sludge and treated product on a bench-scale level; they are currently providing technical consultation for disposing of Duquesne's lime scrubber sludge. The chemistry of the process has not been revealed because of current patent applications on the additive. The amount of additive required, however, is approximately 3-5% by weight of sludge solids. The exact amount depends on the pH of the sludge, % solids desired, and initial solids content. It is reported that following chemical addition to the settler underflow (35-40% solids), the sludge can be pumped 10 kilometers or further to a disposal site, preferably an area which can be dammed up. Curing time is approximately 30 days; the sludge sets up underwater, forcing excess water to the surface, where it can then be drained off.

The economics associated with this process are quoted by Dravo as $1.10-3.30 per metric ton of sludge (35-40% solids) as received from the clarifier from the clarifier underflow (LO-077). This is for a total disposal systems, including capital and operating expenses for a pumping situation. Duquesne, however, has estimated their costs for sludge disposal to be much greater, as high as $16.50 per dry metric ton (AE-012). The basis of this cost is not clear.

Chemfix Corporation markets a proprietary fixation process for conversion of various industrial sludges to stable landfill using at least two inorganic chemicals, one liquid and one powder. Little information is available on the chemistry of the system, although one source reports that "lime and silicates apparently are not used" (TR-026). Polyvalent metal ions react with Chemfix process chemicals resulting in a stable insoluble, inorganic compound within three days, although gelation time can vary with the system being treated. Certain species, including chlorides, monovalent cations, colloidal material and some organics, cannot be fixed by this treatment. At present, Chemfix is not working on an industrial scale with any utilities on scrubber sludge disposal although it has been applied to other types of problems.

The price range quoted by Chemfix for their services is 0.5-2.5¢/ℓ or on the average of 1¢/ℓ for a sludge of high solids content (TR-026). This is equivalent to ~$5.50/metric ton (30-50% solids) (AE-012). This figure does not include costs associated with hauling the fixed material to an off-site landfill.

Comparative evaluations of several of these processes are currently being planned or carried out in the laboratories of Aerospace Corporation under contract to EPA (Contract No. 68-02-1010) and in an independent study by Combustion Engineering, Inc. Aerospace plans to have sludge samples from four different power plants conditioned by at least two commercial processes. Testing of the treated samples will then be performed by Aerospace to determine the following characteristics:

- soluble components
- permeability
- water retention
- compression strength
- bulk density
- detoxification assessment, if appropriate.

Sludge Handling and Transport

Transport of waste scrubber sludge to the ponding site can be carried out by sluicing operation, i.e., piping the slurried solids. This method is also being considered for transport of sludge to the fixation site. Individual sludge properties such as viscosity, velocity, temperature, composition, particle size, and solids concentration affect the pumping characteristics of the material. Also of major concern is the distance to be covered. Special problems specifically related to sulfur oxide sludges such as corrosion or erosion potential also require investigation. Dravo Corporation is investigating the transport of fixed sludges to the disposal site by pipeline. Acid mine drainage sludge, sewage sludge, reslurried phosphogypsum, taconite tailings, and, in many cases, coal ash are transported to the waste disposal area via pipeline or in some cases, open trenches where gravity rather than hydraulic pressure is the moving force.

Transport of sludge to a landfill site via truck is one of the approaches being considered by utilities if off-site disposal is used. The results of one study are available at this time (TA-040). Combustion Engineering transported 68 metric tons (75 tons) of waste (50% sludge, 50% ash) from the limestone scrubber at Kansas Power and Light's Lawrence facility to Dulles Airport in Washington, D. C., a distance of approximately 2,100 km (1,300 miles). Two types of vehicles, flat- and round-bottomed trucks, were employed in order to compare the effect of various features on handling characteristics. Prior to loading, the untreated sludge had been stored in a settling pond at the utility site for six months. It was dredged up and allowed to drain for 24 hours before loading. At various intervals during the non-stop trip measurements and samples were taken. No leakage of sludge was observed although excess water drained from the tailgate while on the road. Unloading problems were encountered with the flat-bottomed trucks; complete removal of the sludge necessitated manipulation with a backhoe. The sludge slid out readily, however, from the round-bottomed trailers.

Coal ash is often trucked to the disposal site. The problems encountered with this waste (fugitive dust, e.g.) are not the same as those which would be involved in scrubber sludge transport by truck. Costs, however, may be comparable.

Conveyor belts and related bucket elevators are potential modes of transport for dewatered sludge over short distances. Potential areas of use include conveying of dewatered solids to a fixation facility, lifting of wastes to hoppers or mixing devices, and transport of fixed sludge to landfill sites. The water content of the sludge is the major factor determining feasibility of this application. If the nature of the sludge is such that water drains in large amounts, precautions such as installation of troughs below the conveyors must be taken to avoid potential water pollution problems.

Other handling aspects which could be mentioned in this discussion are alternate methods of transporting the waste from the scrubber site to the ultimate disposal site. Encompassed in this category would be barge and rail. Both would be feasible only in unique situations where geography and surrounding environment would permit such application.

11.2.2.2 Environmental Aspects of Landfilling Sludge

Water Pollution

Disposal of sludge generated by lime/limestone scrubbing systems in landfill sites creates two potential areas of water pollution, leachate to groundwater and runoff to surface water. Careful evaluation of available research results associated with both runoff and leachate must be made in order to assess any potential environmental hazards which may exist. In this section, information pertaining to factors of water pollution and effect of chemical and physical properties of stabilized scrubber sludge/fly ash mixtures are discussed. Also presented here are possible control measures which have had application in disposal of sludge or other solid waste materials.

In order to predict leachate characteristics of a landfill, it is first necessary to describe the general features of water movement and geological considerations for this disposal method. Due to the recent surge of ecological interest in sanitary landfills utilized for solid waste disposal, there is an abundance of information available. Emrich's review of research in this field presents an overall view of progress on this subject (EM-003). The case studies presented in Sections 2.3 and 3.4 indicate the research being conducted toward the definition and solution of this problem. The future results to be obtained from these projects will shed a great deal of light on the impact of scrubber sludge leachate. Results available to date, however, are not sufficient to fully assess the extent of this problem.

The first consideration when looking at the potential impact of landfill leachate is the volume of leachate that will be produced. This is a direct function of the amount of water reaching the landfill. There are two possible sources of this water: rainfall and naturally occurring subsurface flow through the landfill site. Subsurface flow is a natural phenomenon which can seriously interfere with safe operation of landfills in two ways. First, it is a source of additional volume of potentially harmful leachate. The second consideration is that it can serve as a direct means of groundwater contamination. Prevention can be effected by thorough geologic study of the site beforehand and, if needed, installation of rerouting devices for the groundwater flow. In a similar vein, coverage of the landfill area when complete will greatly reduce, if not eliminate, the amount of leachate produced.

Infiltration and permeability characteristics of the landfill material determine the relative amounts of runoff versus leachate as well as the leaching rate. Reductions in permeability of sludges stabilized by I. U. Conversion System's process and by Dravo's process have been reported (AE-006, MI-084). IUCS's results indicate not only the low permeability values of the fixed scrubber sludges ($\sim 10^{-7}$ cm/sec after 7 days of curing at 38°C), but also the relatively great reduction (~2 orders of magnitude) in permeability compared to freshly prepared sludge/fly ash mixtures. Dravo Corporation reportedly has obtained permeability values of 2×10^{-8} cm/sec for sludge conditioned in their laboratories with 3% additive (LO-077). This is compared to high quality clays having permeation values of 10^{-7} to 10^{-8} cm/sec versus fly ash for which a representative range is 10^{-2} to 10^{-3} cm/sec.

For each of the above processes, it is claimed that soluble components are immobilized in the treatment process. Specific data to support these claims have been reported by I. U. Conversion Systems. Chemfix Corporation has furnished leachate analyses of potentially toxic elements to Radian for specific treated sludges. No data from Dravo or Chicago Fly Ash were available for release at this time.

Land Reclamation Aspects

Certain aspects of land reclamation following abandonment of a landfill site or dried up pond used for scrubber sludges may lead to potential problems. These aspects may be assessed by examining the engineering, physical, and chemical natures of treated and untreated sludge. At the present time no attempts have been made to reclaim land committed to scrubber sludge disposal.

Disposal sites for other solid wastes studied including municipal waste, coal refuse, phosphate slimes, taconite tailings, and coal ash have been successfully reclaimed. Extensive research in these areas is being carried out. The degree of reclamation possible varies with the characteristics of the waste. For example, phosphate slimes areas can support vegetation, but they lack the strength required for building construction. They are used with great success, however, as recreational areas. Reclaimed culm piles have not been evaluated as far as support of buildings is concerned; all work to date conducted by the Bureau of Mines has been concentrated on agricultural usage. These studies have been extremely successful.

Reclamation procedures for municipal waste sanitary landfills require placement of a cover material since the refuse itself will not support vegetation. Phosphate slimes, on the other hand, provide all the nutrients necessary for plant life; reclamation of these areas, however, requires addition of tailings to effect a sufficient degree of dewatering and to lend support to the material. The taconite industry reclaims its tailings areas by draining the readily settling waste. Since the tailings have no nutrient value of their own, extensive fertilizer applications must be made. Coal ash, on the other hand, is currently under investigation to determine the extent of its ability to support vegetation with or without addition of fertilizer and soil conditioners.

One consideration is the tendency of dried scrubber sludge to absorb water with which it comes in contact. As discussed in previous sections of this report, sulfur oxide sludges are relatively difficult to dewater. One sludge sample was observed over a period of several months during which time little or no settling took place after the first 48 hours. Preliminary results of one TVA study indicated that dry solids from a limestone scrubber sludge do not expand when submerged in water or exposed to rainfall (SL-034). Drainability studies conducted by Aerospace, on the other hand, resulted in retention of enough water by dried Shawnee limestone sludge to return to its original water content. The calculated water retention for sludge with underdrainage was 51.7% (AE-007). Behavior of chemically stabilized sludge samples is expected to be greatly improved although specific tests for rewatering potential have not been reported. A practical consideration in regard to rewatering is that for a thick layer of dried sludge, an accumulation of a few meters of rain might be required for rewatering. With proper design of the site plus some low permeability cover material (clay, plastic, or treated sludge) even untreated sludge might never rewater since the small amount of water collected during a rain should be lost by evaporation before the next rain.

A second consideration in land reclamation of sludge disposal areas is the weight which can be supported by the site. This factor can be determined by measuring the pozzolanic strength, compaction strength, and penetration resistance of the throwaway product. The strength associated with any landfill or construction material is a function of composition, moisture content, and compacted density.

Untreated scrubber sludge has been shown to lack any appreciable degree of compressive strength based on studies performed by Aerospace on Shawnee and Mohave samples (AE-009). Samples subjected to the I. U. Conversion Systems' fixation process have been tested for various strength characteristics with good results (MI-084). In addition to producing greater strengths, the treatment process also resulted in shorter curing times. Another consideration in an engineering evaluation is scructural integrity. Experimental data which can be used to describe this characteristic are dimensional stability measurements and field testing. Untreated sludges reportedly have very poor dimensional stability. On exposure to drying conditions, shrinkage and cracking was observed (AE-006). This phenomenon can be prevented by addition of a pozzolanic material such as is involved in most of the stabilization processes now offered. Field tests to date have produced good results with regard to structural integrity.

An additional factor to be considered in reclamation of abandoned sludge disposal sites is whether growth of vegetation can be supported on the area. At the present time no studies are available directly concerning this aspect.

11.3 Alternate Disposal Techniques

Several other possible options are available for disposal of air pollution control system sludges although they are not under investigation to the same extent as landfill and ponding. These alternatives involve direct deposit of the waste below the surface in subsurface mines or utilization of the sludge to reclaim strip mine areas. Another possible solution is commercial utilization. Development in this area is currently in progress under both government sponsorship and private industry.

Deep mine filling has been used for the disposal of power plant ash (HA-158) and acid mine drainage sludge. In the first case, ash is sluiced into the mine through boreholes. Normally, gravity is sufficient to create a flow into the mine. Pumps and additional boreholes were provided in case of hole plugging or increased friction losses. A dewatering sump and a settling basin were formed by constructing dams across the mine flow. Overflow from the settling basin flows to the sump from which it is pumped to an above-ground basin. Acid mine drainage sludge is disposed of in deep mines in several cases where such sites are available adjacent to the treatment plant.

This type of approach may not be directly applicable to disposal of lime/limestone scrubber sludges for several reasons. First, the viscosity of this waste is such that it is probable that it would not spread laterally throughout the mine disposal area. Secondly, the settling characteristics have been shown to be poor; ready solid/liquid separation is not expected (Section 11.1.1). This would perhaps decrease the attractive features of a mine subsidence operation in that little geological support would be provided by the sludge. In addition, some environmental hazard may exist due to water pollution aspects. Possibly the last two foreseeable problems could be avoided or reduced by a fixation treatment. Investigation of this approach may be worthwhile to those utilities to which abandoned deep mines are available as a possible disposal site.

Reclamation of strip mine areas with waste sludge is another possibility. This could be viewed as a specialized landfill operation; as was discussed in the preceding section, it is not yet certain whether or not pretreatment of the sludge will be required for strength development and to prevent environmental contamination. The benefits of this type of disposal are obvious, however, if shown to be a feasible approach. In addition, land availability would not be a problem in many areas of the nation. Strip mine reclamation with fly ash has been in practice for many years now, much of it under the development of the Bureau of Mines. The case study discussed in Section 3.4 is a project utilizing sewage sludge to reclaim strip-mined areas. Results to date seem successful, although leachate is under extensive investigation. Acid mine drainage sludge is another potential candidate for mined land reclamation because of its neutralizing capacity. As discussed in Section 5.4, preliminary work has been done in this area. Additional development is needed for utilization (disposal) of scrubber sludges in this capacity.

The alternative to disposal of scrubber sludges is development of commercially applicable utilization processes.

Numerous programs in this area have been conducted through government sponsorship and by industry alone. These are summarized in Table 11-4.

Combustion Engineering and I. U. Conversion Systems (formerly G&WH Corson), in cooperation with the Research and Development Division of the Federal Highway Administration, studied the potential of several industrial sulfate sludges as highway construction materials (TA-040, BR-112).

In one section of the Dulles Airport in Washington, D. C., a mixture of lime (3%, dry basis), SO_2 scrubber sludge (8%), fly ash (59%), and aggregate (30%) was tested as a road course material. The sludge was a 50% solids slurry obtained from Combustion Engineering's limestone scrubbing system at Kansas Power and Light's Lawrence facility. The paving mixture was placed in a seven-inch layer over a compacted subgrade, compacted to five inches, and sealed with a bituminous material to prevent water infiltration. Less than completely satsifactory results were obtained, however, primarily because of excessive rainfall during construction. Despite these problems, however, the demonstration project served to firmly establish the feasibility of this utility scheme.

IUCS offers a process called Poz-O-Tec* to convert power plant scrubber sludge to stabilize structural fill material or to usable manufactured by-products. The process is based on technology of the Poz-O-Pac® process which is also a fly ash stabilization technique. The product of the Poz-O-Tec* process, Sulf-O-Poz®, can be used as a stabilized fill material. It possesses certain structural qualities

TABLE 11-4

SLUDGE UTILIZATION SCHEMES

I. FILLER MATERIAL
  A. Structural Fill
  B. Mine Void Fill
  C. Filler in Bituminous Concrete
  D. Waste Disposal/Sanitary Structural Land Fill

II. Pozzolanic Products
  A. Road Base Course

III. Autoclave Products
  A. Concrete Admixture (Structure and Products)
  B. Fired Brick
  C. Lightweight Aggregate

IV. Pressure Sintered Products
  A. Metal Coatings
  B. Pipes

V. Gypsum Products
  A. Plaster
  B. Wallboard

VI. Soil Amendment

VII. Mineral Wool

TABLE 11-4
(Cont.)

VIII. Mineral Recovery

- A. Lime
- B. Aluminum
- C. Iron
- D. Pozzolan (glass particles)
- E. Titanium
- F. Silicon
- G. Rare Elements

IX. Sulfur Extraction

- A. Sulfur
- B. Sulfuric Acid

X. Polluted Water Treatment

- A. Recovery of polluted streams, ponds, lakes
- B. Neutralization of Acid Mine Drainage and Polluted Waters
- C. Sewage Plant Treatment

permitting its use in some cases as structural embankments, land reclamation projects, and liners for ponds and reservoirs. Sulf-O-Poz® can be further processed to produce cementitious material of other compositions such as synthetic aggregate suitable for production of structural shapes, portland cement or asphaltic concrete. Sulf-O-Poz® may also be supplied directly for use as stabilized road base required in primary highways, airport runways, trucking terminals, and similar applications.

Gypsum is one of the solid by-products of the wet lime/limestone gas desulfurization process. This material can be recovered although the feasibility of doing so is limited by the amount of foreign material in the sludge, i.e., fly ash, unreacted lime or limestone, and calcium sulfite. Elimination of fly ash can be achieved by burning oil rather than coal or by installing efficient electrostatic precipitators upstream of the scrubber unit. Oxidation of sulfite to sulfate is currently practiced in Japan and is under investigation in this country as well. The fly ash elimination and oxidation processes result in a clean grade gypsum, $CaSO_4 \cdot 2H_2O$, which is used in making wallboard, wall plaster, or as a cement additive for construction use. This approach has already been taken in Japan. In one plant sulfite is oxidized to sulfate in special equipment. Similarly, sulfite oxidation equipment is being installed at the Mitsui Aluminum Plant in Japan. It was recently predicted, however, that the Japanese supply of gypsum will soon exceed the demand (AN-059). The economics of this utilization process may not be acceptable in the United States where there exist large natural sources of relatively pure, dry gypsum. Moreover, if an efficient precipitator is not employed, the dark color of gypsum due to fly ash and other impurities could be a significant problem for a potential gypsum market. The economics of the utilization are more favorable in the Chiyoda and Hitachi processes where the gypsum is manufactured from sulfuric acid and hence the oxidation step is circumvented.

By-product gypsum from phosphoric acid manufacture has been investigated by the phosphate industry with regard to potential utilization schemes. Although this research has been in progress for a number of years, no feasible method has been found as yet.

The potential utilization technologies described up to this point are fairly well established in that they are either commercially practiced or have at least been successfully demonstrated on a large test scale. A list of less promising schemes which have been suggested include autoclaved products (brick, aerated concrete, poured concrete); mineral wood; soil amendment and stabilizer. Although several possible markets for scrubber sludge could develop, it is likely, however, that the growth of these markets will lag far behind the growth of sludge production, resulting in the great majority of sludge being disposed of as a throw-away product.

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